UM-8

UNIT HYDROGRAPH DERIVATION

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ABSTRACT

The unit hydrograph technique is a simple tool being used by most of the water resources development organisations for the estimation of flood flows. Although number of techniques are available for finding the unit hydrograph, but all of them have some advantages as well as limitations. The technique adopted for the derivation of unit hydrograph in this user manual is based on Nash's approach as it gives non-oscillating and physically realizable unit hydrograph.

Nash considered that the Instantaneous Unit Hydrograph (IUH) can be obtained by routing the unit impulse input through a cascade of N linear reservoirs of equal storage coefficient K. Thus, the two parameters, N and K, determine the shape of the unit hydrograph. These parameters are estimated in the user manual by (i) method of moment, and (ii) optimization procedure. The former method requires the first and second moments of input (excess rainfall) as well as output (direct surface runoff), which are used in solving the moment expressions to get parameters N and K. However, in the latter approach the set of parameters, N and K, are estimated minimizing the objective function i.e. the sum of squares of the differences between ordinates of observed and computed hydrographs using Quasi Newton optimization procedure. The computer programmes NASH.FOR and CONTI.FOR, based on the above two methods

have been developed at the National Institute of Hydrology, Roorkee and have been tested on VAX-11/780 system for the test input. The programmes require the stations rainfall alongwith their Thiessen weights and observed discharge hydrographs for the isolated events as input. The data interval for the observed rainfall hyetograph and observed discharge hydrograph should be the same. The programmes give the following outputs; the base flow hydrograph, direct surface runoff hydrograph, excess rainfall hyetograph, the parameters N and K, IUH and UH (Unit Hydrograph) ordinates and computed discharge hydrograph. The programme also estimates the error functions such as: (i) model efficiency, (ii) average standard error, (iii) average absolute error, (iv) average percentage absolute error, (v) percentage absolute error in peak, and (vi) percentage absolute error in time to peak. The input and output specifications for the programmes have also been described. The programmes can be run on computers other than VAX-11/780 system having FORTRAN compiler, after making suitable modifications.

1.0 INTRODUCTION

The estimation of flood flows resulting from the rainfall is required in the planning, design and operation of water resources projects. The unit hydrograph technique is a simple tool being used by most of the water resources development organisations in different countries for estimation of direct surface runoff. Unit hydrograph, by definition, is the direct surface runoff hydrograph that would be observed at the outlet of the drainage area as a result of unit rainfall excess falling uniformly over the catchment in space as well as in time within the specified duration. The unit hydrograph technique assumes the catchment as a linear system which transforms the rainfall input into direct surface runoff as an output. It is well known that assumption of linearity involved in the unit hydrograph technique do not accurately apply for the natural watersheds. Inspite of the assumption of linearity, analysis of field data indicates that the unit hydrographs derived from different storms are not identical and are sensitive to data errors. Inspite of its limitations, unit hydrograph is a powerful and practical tool for predicting flood flows if it is applied with care and proper judgement.

1.1 Purpose and Capabilities

Various techniques are available in the literature for deriving the unit hydrograph. Nearly all of them have some limitations. In selecting a particular technique for the derivation of unit hydrograph it is preferable to satisfy amongst others, the following requirements:

i. The unit hydrograph ordinates are all positive.

ii. The shape of the unit hydrograph is preserved.

iii. The errors in input data are not amplified during the unit hydrograph derivation.

iv. The method is capable of admitting a number of events simultaneously for the unit hydrograph derivation.

v. Computationally, the method is simple, efficient and easily programmable.

Each technique has its strength and weaknesses and does not satisfy all of the above requirements. The purpose of this user manual is to provide the guidelines for derivation of unit hydrograph using one of the well known techniques which fulfil most of the above mentioned requirements. The technique used for the derivation of unit hydrograph in this user manual is based on Nash's approach which considers the response of the catchment as due to routing of the inflow through a cascade of equal linear reservoirs. The two parameters, N (no. of equal linear reservoirs) and K (storage coefficient for each linear reservoirs), define the shape of the unit hydrograph, which is physically realizable. The two parameters N and K are estimated using (i) method of moments, and (ii) optimization procedure. There are two separate computer programmes for each of these methods. The computer programme based on optimization procedure has the capability of admitting a number of events simultaneously for the derivation of the representative unit hydrograph for the catchment. The computer programme based on method of moment is capable of analysing the several storms of a catchment in a single run. There are two options available in the programme: i) calibration option; and ii) test option. The first option of the programme provides an estimate of the parameters N and K for each of the storms selected for the calibration using method of moments. However, the second option of the programme may be used to test the performance of average parameters, N and K, of the model in reproducing the independent storms which are not included in the calibration. The average values of parameters N and K, which are considered as the input to the programme while running it for the second option, may be computed by taking either the geometric means or arithmatic means of the values N and K for the storms used in calibration.

1.2 Definitions of Terminology

a. Unit hydrograph - As defined earlier, it is a hydrograph of direct surface runoff resulting from unit excess rainfall falling uniformly over the catchment in space as well as in time for a specified duration.

b. Instantaneous unit hydrograph - It is a unit hydrograph of infinitesimally small duration.

c. Excess rainfall - The part of the rainfall which appear over the surface as runoff and later on contribute to the stream of the catchment.

d. Direct surface runoff - The runoff resulting at the catchment outlet due to excess rainfall.

e. Linear reservoir - The reservoir in which the storage is assumed to be directly proportional to the discharge.

f. Model efficiency - The model efficiency is, mathematically, defined as:

$$E = (F_0 - F_1')/F_0 \qquad \text{...(1a)}$$

$$F_0 = \sum_{i=1}^{n} \{ Q_0(i) - \bar{Q} \}^2 \qquad \text{...(1b)}$$

$$F_1 = \sum_{i=1}^{n} \{ Q_0(i) - Q_c(i) \}^2 \qquad \text{...(1c)}$$

where, $Q_0(i)$ and $Q_c(i)$ are i^{th} values of observed and computed discharges respectively, $\bar{Q}$ is the mean of n values of observed discharges, E is the model efficiency, F_0 is the sum of the squares of the differences between observed discharges and mean discharge, and F_1 is the sum of the squares of the differences between observed discharges and computed discharges using the model.

g. Average Standard error- It is the root mean squared sum of differences between observed and computed hydrographs.

h. Average absolute error - It is the average of the absolute values of the differences between observed and computed hydrographs.

i. Average percentage absolute error - It is the average of the absolute values of percent differences between computed and observed hydrograph ordinates.

j. Percentage absolute error in peak - It is the ratio of the absolute difference in observed and computed peak and observed peak.

k. Percentage absolute error in time to peak - It is the ratio of the absolute difference between observed and computed time to peak and observed time to peak.

l. Objective function - It is the sum of the squares of the differences between observed and computed discharges as given in equation (1c).

m. Base flow - It is that contribution to a stream flow hydrograph which results from releases of water from sub-surface storage.

1.3 Scope

The methods employed for the derivation of unit hydrograph consider the rainfall as an lumped input. The programmes require the observed rainfall at each raingauge stations and corresponding Thiessen weights alongwith the stream flow discharge data at the same sampling interval. The unit hydrograph derived from the particular data set will have the duration of sampling interval. The programmes estimate the following main components:

i. Base flow

ii. Direct surface runoff

iii. Excess rainfall

iv. Uniform loss rate

v. Total rainfall excess

vi. The model parameters, N and K

vii. IUH and UH ordinates, UH peak and time to peak

viii. Computed discharge, observed and computed peak and time to peak.

ix. The errorfunctions which are:

a. Model efficiency

b. Average standard error

c. Average absolute error

d. Average percentage absolute error

e. Percentage absolute error in peak and

f. Percentage absolute error in time to peak

2.0 DERIVATION OF UNIT HYDROGRAPH USING NASH MODEL

2.1 General Description

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

$$U(T,t) = \frac{1}{T}\{ I(N,t/K) - I(N,(t-T/K)) \} \qquad \ldots(2)$$

where,

$U(T,t)$ = t^{th} ordinates for the unit hydrograph of duration T,

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

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

It can be seen from the above equation (2) that the unit hydrograph of duration T may be derived only when the values of two parameters, N and K, are known. Two methods, namely, method of moments and optimization method, are used for the purpose of the parameter estimation. The unit hydrograph ordinates obtained from the above equation are convoluted with the excess rainfall in order to get the computed direct surface runoff. The equation which relates the excess rainfall, unit hydrograph and direct surface runoff is given as:

$$Q(i) = \sum_{i=1}^{n} \sum_{j=1}^{i} U(j) * X(i-j+1) \qquad \ldots(3)$$

where,

$Q(i)$ = direct surface runoff at basin outlet at the end of computation interval i,

$U(j)$ = j^{th} ordinate of unit hydrograph,

$X(i)$ = average rainfall excess for computational interval i, and

n = number of rainfall excess ordinates.

2.2 Data Requirements

The data required for running the first computer programme is to be described in the following form for different storms in a particular catchment for first option of the computer programme for calibration,

i. Catchment Area (km^2)

ii. Data interval (hrs.)

iii. Number of storms to be analysed

iv. Number of raingauge stations and corresponding Thiessen weights (sum of weights must be equal to one), for the first storm

v. Number of rainfall records for first storm

vi. Rainfall depths (mm) at time interval given in (ii) at each raingauge stations for the first storm

vii. Number of discharge hydrograph ordinates for the first storm

viii. Ordinates of discharge hydrograph (m^3/s) for the first storm at time interval given in (ii)

ix. Repeat steps (iv) to (viii) for each of the storms

For the second option (wherein testing is done) of the first computer programme based on method of moments the average values of parameters, N and K, are also required as an additional information alongwith the above mentioned information for independent data of storms not used in calibration.

The second computer programme based on optimization technique requires an initial estimate of the parameters along with the data, as mentioned above, for the calibration runs. The programme gives the values of representative parameters and unit hydrograph ordinates for the catchment corresponding to the minimum value of objective function evaluated from the data of storms (one or more in number) provided for calibration.

2.3 Analysis

The analysis procedure used in the programme is as follows:

a. Estimation of effective rainfall and firect surface runoff - The average rainfall during the storms is obtained by taking the weighted mean of the observed values at different stations. The next step is to separate base flow from discharge hydrograph to get direct surface runoff. The method used here for baseflow 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 separation of abstraction from rainfall is done by using the uniform loss rate. A trial and error procedure is adopted to locate the starting point of rising hydrograph to be the same as the start of the effective rainfall and the infiltration rate is adjusted such that the volume of effective rainfall equals the volume of direct surface runoff. If during the trial it is found that this 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.

b. Estimation of parameters - The parameters, N and K, of the Nash model are estimated using the following procedure for two methods viz. (i) method of moments, and (ii) optimization method.

i. Method of moments

Theorem of moments introduced by Nash (1959), is used to relate moments of input and output with moments of impulse response. The equations used are:

$$_1M'_y - {_1M'_x} = NK \qquad \text{...(4)}$$

$$_2M'_y - {_2M'_x} = N(N+1)K^2 + 2NK\ {_1M'_x} \qquad \text{...(5)}$$

where,

$_1M'_y$ and $_2M'_y$ = first and second moment about the origin of the direct surface runoff hydrograph respectively, and

$_1M'_x$ and $_2M'_x$ = first and second moment about the origin of the effective rainfall hyetograph respectively.

The equations for n^{th} moment about the origin of the effective rainfall hyetograph and direct surface runoff hydrograph are:

$$_nM'_y = \frac{\sum_{i=1}^{M} \frac{y_i + y_{i+1}}{2} \Delta t \; t_i^n}{\sum_{i=1}^{M} \frac{y_i + y_{i+1}}{2} \Delta t} = \frac{\sum_{i=1}^{M} \bar{y}_i \; t_i^n}{\sum_{i=1}^{M} \bar{y}_i} \quad \ldots(6)$$

$$_nM'_x = \frac{\sum_{i=1}^{m} x_i \; \Delta t \; t_i^n}{\sum_{i=1}^{m} x_i \; \Delta t} = \frac{\sum_{i=1}^{m} x_i \; t_i^n}{\sum_{i=1}^{m} x_i} \quad \ldots(7)$$

where,

$\bar{y}_i$ = Uniform rate of runoff for the i^{th} interval,

M = Number of runoff intervals,

n = n^{th} moment about the origin,

t_i = time to the mid point of the i^{th} interval from the origin,

m = number of rainfall blocks, and

Δt = time interval.

Putting n equal to one and two in the above equations gives first and second moment about the origin of effective rainfall hyetograph and direct surface runoff hydrograph respectively. Substituting these values of moments in equations (4) and (5) and solving these equations the values of parameters N and K are obtained. The computer programme NASH.FOR uses this procedure to estimate the parameters N and K.

ii. Optimization method

In this procedure the parameters are estimated by minimizing the sum of the squares of differences between observed and computed hydrographs using data of all storms used in calibration using Quasi Newton optimization procedure. The programme requires some initial estimate of parameters, N and K, and estimates the parameters by searching in the direction of steepest gradient of the objective function for its minimum value.

The computer programme CONTI . FOR uses the above procedure to estimate the parameters and corresponding unit hydrograph ordinates.

c. Estimation of unit hydrograph ordinates - Both of the programmes estimate the unit hydrograph ordinates using the following equation:

$$U(T,t) = (1/T)\{I(N,t/K) - I(N,(t-T)/K)\} \quad \ldots(8)$$

where,

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

$I(N,t/K)$ = incomplete gamma function of order N at (t/K) etc.

The unit hydrograph ordinates are estimated in the SUBROUTINE DUHGAM using the above equation. The subroutine for incomplete gamma function computation is called in this subroutine.

d. Estimation of computed discharge hydrograph - The computed discharge hydrograph is obtained by adding the corresponding base flow hydrograph ordinates to the direct surface runoff hydrograph ordinates estimated using the following equation:

$$y_i = \sum_{i=1}^{m} \sum_{j=1}^{i} U(j) * X(i-j+1) \quad \ldots(9)$$

where,

y_i = computed direct surface runoff

$U(j)$ = j^{th} ordinate of unit hydrograph of duration T hours,

$X(i)$ = excess rainfall for computation interval i of T hour duration, and

m = number of rainfall excess ordinates .

e. Estimation of error functions - After computing the discharge hydrograph ordinates, the provision has been made in the programme for computation of the following error functions, which have been defined earlier in section 1.2 :

(i) Model efficiency, (ii) Average standard error, (iii) Average absolute error , (iv) Average percentage absolute error, (v) Percentage absolute error in peak, and (vi) Percentage absolute error in time to peak.

2.4 Advantages and Limitations

The advantages of this method for the derivation of unit hydrograph are:

i. It always estimates ordinates of unit hydrograph as positive ordinates.

ii. It preserves the shape of the unit hydrograph.

iii. The errors in input data are not able to distort the shape of the unit hydrograph.

iv. The optimization procedure based method is capable of admitting a number of storm events simultaneously for the representative unit hydrograph derivation.

v. Since only two parameters define the complete shape of the unit hydrograph, therefore, the parameters obtained from the gauged basins of the region can be easily correlated with catchment characteristics of the basin in order to get the regional relationships for use in derivation of the unit hydrographs for the ungauged basins of the region.

The limitations of the methods for the derivation of the unit hydrograph discussed in this report are mostly related to assumptions of unit hydrograph theory. As far as possible storms for the unit hydrograph derivation have to be intense and of short duration. However, such storms are rare in practice. Therefore, one has to use the complex storms for deriving the unit hydrograph. The technique should not be applied as it is to derive the representative unit hydrographs for those catchments which indicate highly non-linear behaviour. This will necessitate suitable modifications to change the parameters with rainfall input etc.

If optimization procedure is being used for the estimation of the parameters, then one may need to study the variation in the objective function with different sets of initial parameters in order to get optimum solution.

3.0 RECOMMENDATIONS

The programmes for derivation of unit hydrograph using Nash model can be used to derive unit hydrograph for small catchments using the storm rainfall-runoff data, as far as possible, for intense and short duration storms. The programmes have been developed at National Institute of Hydrology, Roorkee and tested on VAX-11/780 computer system. The programmes may run on other computer system, having fortran compiler, after suitable modifications as per the software requirements of the system.

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APPENDIX I

DETAILS OF COMPUTER PROGRAM FOR NASH MODEL USING METHOD OF MOMENTS

A. DESCRIPTION OF COMPUTER PROGRAMME

The computer programme NASH.FOR is written in FORTRAN-IV language and run on a Digital Equipment's VAX-11/780 system. The programme derives the unit hydrograph using Nash's concept of cascade model and also estimates the computed hydrograph ordinates and the values of the error functions. The main variables used in the main programme are described below:

VARIABLE	DESCRIPTION
CA	Catchment area
DLT	Sampling interval
D	Unit hydrograph duration
AN	Parameter N for the Nash model
AK	Parameter K for the Nash model
NST	Number of storms to be analysed
CB	Flow at recession point of the falling limb
NSTAT	Number of raingauge stations
WT	One dimensional array containing the Thiessen weights of each raingauge stations

NRAIN	Number of rainfall blocks measured at the rain-gauge stations
RAIN	Two dimensional array containing the values of rainfall blocks at each raingauge stations
EFR	One dimensional array containing average values of rainfall blocks
NRUN	Number of ordinates of observed discharge hydrographs
OBD	One dimensional array containing the discharge hydrograph ordinates
BFLO	One dimensional array containing the base flow at each computational interval
EXR	One dimensional array containing the effective rainfall blocks
ODSRO	One dimensional array containing the direct surface runoff ordinates
QM1	First moment of direct surface runoff hydrograph about the origin
QM2	Second moment of direct surface runoff hydrograph about the origin
RM1	First moment of effective rainfall hyetograph about the origin
RM2	Second moment of effective rainfall hyetograph about the origin
UIR	One dimensional array containing IUH ordinates
UHS	One dimensional array containing the unit hydrograph ordinates
CDSRO	Single array having computed direct surface runoff
COMPD	Single array containing computed discharge

hydrograph ordinates

STE	Average standard error
ABE	Average absolute error
ABPE	Average percentage absolute error
PEPEAK	Percentage absolute error in peak
PETPEAK	Percentage absolute error in time to peak

The main programme calls various subroutines for different operations. The purpose of each subroutines and the description of the variables used as arguments of the subroutine is given below:

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

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

Q	A vector of observed discharge hydrograph ordinates
BF	A vector of base flow ordinates
DRO	A vector of direct surface runoff hydrograph ordinates
NNRUN	Number of discharge hydrograph ordinates
NNBEG	The ordinates number at which the effective rainfall starts contributing the direct surface runoff after satisfying the requirement of initial loss
TTIME	The computational times vector
CB	Flow at recession point on the falling limb

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

This subroutine separates the loss using ϕ-index method and computes the effective rainfall hyetograph. The variables used in arguments are described as:

EEFR A vector of average rainfall hyetograph

SSDSRO Total direct surface runoff as an equivalent depth in mm.

DDLT Computational interval

EEXR A vector of effective (excess) rainfall hyetograph

NNBEG As defined in subroutine RUNSEP

NNRAIN Number of average rainfall blocks

AAINFR Uniform loss rate (ϕ-index)

SSRX Total volume of excess rainfall in mm

iii. SUBROUTINE MRUN (DSRO, NB, N, DELT, DM1, DM2)

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

DSRO A vector of direct surface runoff hydrograph

NB The same as NNBEG in SUBROUTINE RUNSEP

N Number of discharge hydrograph ordinates

DELT Computational interval

DM1 The first moment of direct surface runoff hydrograph about the origin

DM2 The second moment of direct surface runoff hydrograph about the origin

iv. SUBROUTINE MRAIN(REX, N, DELT, DR1, DR2)

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

REX   A vector of excess rainfall hyetograph

N   Number of rainfall blocks

DELT   Computational interval

DR1   The first moment of excess rainfall hydrograph about the origin.

DR2   The second moment of excess rainfall hyetograph about the origin.

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

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

DUH   A vector of D-hour unit hydrograph ordinates

NDUH   Number of unit hydrograph ordinates

PN   Number of linear reservoirs

PK   Storage coefficient for a single linear reservoir

D   Duration of unit hydrograph

IER   An integer on return tells whether or not the solution is found to be accepted. IER=0 on return, then the solution has been accepted .

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

SUBROUTINE ICGAMA (A, X, GAMI, IER)

where, A the value for which the incomplete gamma function is required.

X the upper limit of the integeration

GAMI the computed approximation to the incomplete gamma function

IER a parameter which indicates whether an error condition occurred during the execution of this routine. If IER=0 on completion of the routine then every thing went O.K., otherwise some error condition was detected.

The subroutine GAMMA is called inside the subroutine ICGAMA to compute the gamma function value. The subroutine GAMMA is described as:

SUBROUTINE GAMMA (X,GAM, IER)

where, X the real, positive argument for which the gamma function is to be computed

GAM the computed approximation to $\Gamma(X)$

IER Equal to zero for acceptable solution

vi. SUBROUTINE CONVOL (QEST, UHH, REX, NRR)

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

QEST The computed direct surface runoff vector

UHH A vector of D-hr. unit hydrograph

REX A vector of excess rainfall

NRR Number of direct surface runoff to be computed

vii. SUBROUTINE ERROR (OBSQ, COMPQ, N, SE, AE, APE)

This subroutine calculates three error functions from observed discharge and computed discharge hydrographs. The variables used as arguments are:

OBSQ A vector of observed discharge

COMPQ A vector of computed discharge

SE Average standard error

AE Average absolute error

APE Average percentage absolute error

N No. of discharge hydrograph ordinates

viii. SUBROUTINE RANK (Y, N)

This subroutine ranks the set of values in descending order. It is used for identifying the peak and time to peak of the unit hydrograph and discharge hydrographs. The variables used as arguments are:

Y A vector of the values to be arranged in descending order

N Number of the values involved

B. INPUT SPECIFICATIONS

The input is to be supplied in two ways: (i) Through terminal at the time of running the programme interactively (ii) Through an input file.

(i) The details of information to be supplied through terminal interactively are given below:

S.No.	Matter displayed on the terminal	Information to be supplied by the user through terminal
1.	NAME OF INPUT FILE?	Give file name having maximum six characters, for example, A.DAT
2.	NAME OF OUTPUT FILE?	Give a file name having maximum six characters to store the output information, for example, OUT.DAT
3.	CATCHMENT NO.?	Supply the catchment identification not more than ten characters
4.	CATCHMENT AREA?	Supply catchment area(sq.km.) in free format
5.	SAMPLING INTERVAL?	Supply the data interval (same for rainfall and discharge) in free format
6.	DURATION OF UNIT HYDROGRAPH ?	Supply the duration of unit hydrograph (hours)
7.	DO YOU WANT TO CALIBRATE THE MODEL?	Supply either 'YES' for calibration option or 'NO' for test option
a.	AVERAGE VALUE OF N ?	Supply the appropriate value of N in free format
b.	AVERAGE VALUE OF K ?	Supply the appropriate value of K in free format
8.	HOW MANY STORMS HAS TO BE ANALYSED ?	Supply the number of storms to be analysed

Information regarding 7(a) and 7(b) will only be required when user has preferred to use test option.

(ii) The details of information and their specifications which are to be supplied through an input file are:

VARIABLE	FORMAT	DESCRIPTION
CB	FREE	Flow at recession point
NSTAT	FREE	Number of raingauge stations
WT(I)	FREE	A vector of weights of each raingauge stations
NRAIN	FREE	Number of rainfall values at each stations
RAIN(I,J)	FREE	Matrix of rainfall values (mm) observed at different raingauge stations having rainfall values at each stations in each column
NRUN	FREE	Number of discharge ordinates
OBD(I)	FREE	A vector of discharge hydrograph (m^3/s) ordinates

C. OUTPUT DESCRIPTIONS

The specifications for writing the variables in an output file are described below for the two options respectively:

i. Option-I (Calibration option)

VARIABLE	FORMAT	DESCRIPTION
TITLE(I)	10A1	A vector of some numerical or alphabatical characters to be used as identification of the catchment

CA	F8.3	Catchment area (km^2)
ODSRO(I)	10F8.3	A vector of observed direct surface runoff hydrograph (m^3/s)
BFLO(I)	10F8.3	A vector of base flow ordinates (m^3/s)
AINFR	F8.3	Infiltration capacity (mm/hour)
SRX	F8.3	Rainfall excess (mm)
REXR(I)	10F10.3	A vector of separated rainfall values (mm)
QM1	F10.3	First moment of direct surface runoff hydrograph about the origin
QM2	F10.3	Second moment of direct surface runoff hydrograph about the origin
RM1	F10.3	First moment of effective rainfall hyetograph about the origin
RM2	F.10.3	Second moment of effective rainfall hyetograph about the origin
AN	F8.3	Value of N
AK	F8.3	Value of K (hours)
UIR(J)	10F8.3	A vector of IUH ordinates
S7	F12.5	Area of IUH
UIR(NR)	F10.5	I.U.H.peak
JJ	I3	I.U.H. time to peak (hours)
SUMI	F12.5	Area of UH
UHS(I)	10F8.3	A vector of unit hydrograph ordinates (m^3/s)
CCDSRO(I)	F7.1	A vector of computed direct surface runoff hydrograph (m^3/s)

OBD(I)	F7.1	A vector of observed discharge hydrograph (m^3/s)
BBFLO (I)	F7.1	A vector of base flow ordinates(m^3/s) corresponding to each discharge hydrograph ordinates
CCOMPD(I)	F7.1	A vector of computed discharge hydrograph (m^3/s)
UHS(NR)	F5.0	U.H. peak (m^3/s)
K	I2	U.H. time to peak
OBD(NRUN)	F7.1	Observed peak (m^3/s)
J	I2	Observed time to peak (hours)
COMPD(NRUN)	F7.1	Computed peak (m^3/s)
L	I2	Computed time to peak (hours)
EFF	F10.2	Efficiency of the model
STE	F8.3	Average standard error
ABE	F8.3	Average absolute error
ABPE	F8.3	Average percentage absolute error
PEPEAK	F10.2	Percentage absolute error in peak
PETPEAK	F10.2	Percentage absolute error in time to peak

ii. Option-II (Test option)

VARIABLE	FORMAT	DESCRIPTION
TITLE(I)	10A1	As defined for option-I
CA	F8.3	Catchment area (km^2)
ODSRO(I)	10F8.3	As described for option-I
BFLO(I)	10F8.3	As described for option-I
AINFR	F8.3	-do-
SRX	F8.3	-do-

REXR(I)	10F10.3	As described for option-I
AN	F8.3	Average N
AK	F8.3	Average K
UIR(I)	10F8.3	As described for option-I
S7	F12.5	-do-
UIR(NR)	F10.5	-do-
JJ	I3	-do-
SUMI	F12.5	-do-
UHS(I)	10F8.3	-do-
CCDSRO	F7.1	-do-
OBD(I)	F7.1	-do-
COMPD(I)	F7.1	-do-
BBFLO(I)	F7.1	-do-
UHS(NR)	F5.0	-do-
K	I2	-do-
OBD(NRUN)	F7.1	-do-
J	I2	-do-
COMPD(NRUN)	F7.1	-do-
L	I2	-do-
EFF	F10.2	-do-
STE	F8.3	-do-
ABE	F8.3	-do-
ABPE	F8.3	-do-
PEPEAK	F10.2	-do-
PETPEAK	F10.2	-do-

D. TEST DATA

i. Input data for option-I (calibration option)

Catchment number	807/1
Catchment area	823.62 km^2
Sampling interval	one hour
Duration of unit hydrograph	One hour
Number of raingauge stations	5
Thiessen weights of the stations	0.1560 0.1810 0.2720 0.1710 0.220
Number of rainfall values observed at each stations	7

Rainfall values at each stations (mm)

hr.	Stn.1	Stn.2	Stn.3	Stn.4	Stn.5
1.	0	0	2	0	0
2	0	11	0	0	0
3	0	13	6	25	14
4	8	9	15	10	21
5	7	0	3	8	5.5
6	10	0	9	0	11
7	0	12	1	0	1.5

Number of discharge values	20
Flor at recession point	105 m^3/s

Discharge values (m^3/s)

55	55	60	65	142	285	355
370	430	440	285	260	210	170
150	132	120	115	105	100	

ii. Input data for option-II (test option)

Catchment number	807/1
Catchment area	823.62 km^2
Sampling interval	1 hour
Duration of unit hydrograph	1 hour
Average value of N	3.96
Average value of K	1.41 hours
Number of raingauge stations	5
Thiessen weights of the raingauge stations	0.1560 0.1810 0.2720 0.1710 0.220
Number of rainfall values observed at each stations	7

Rainfall values at each stations (mm)

hr.	Stn.1	Stn.2	Stn.3	Stn.4	Stn5
1	0	0	2	0	0
2	0	11	0	0	0
3	0	13	6	25	14
4	8	9	15	10	21
5	7	0	3	8	5.5
6	10	0	9	0	11
7	0	12	1	0	1.5

No.of discharge values	20
Flow at recession point	105 m^3/s
Discharge values (m^3/s)	55 55 60 65 142 285
	355 370 430 440 285 260
	210 170 150 132 120 105
	100

E. **COMPUTER PROGRAMME** NASH.FOR

```
C       NASH MODEL FOR  AVERAGE N AND K- COMPUTATION OF HYDROGRA
C       PHS AND ERRORS AND ALSO CALIBRATION OF THE MODEL
        DIMENSION EXR(50),OBSRO(100),CBSRO(100),BFLO(100),OBB(100)
        DIMENSION COMPB(100),TITLE(50),TIME(100),UIR(100),UR(100),UH(100)
        DIMENSION EFR(50),ABFLO(100),REXR(50),UHH(100),UIRR(100),UIR1(100)
        DIMENSION OOBB(100),CCOMPB(100),UHS(100),WT(50),RAIN(50,50)
        1,CCBSRO(100),BBFLO(100)
        DATA IYES/'YES'/
        CHARACTER *6 FYLE,FYLEN
        WRITE(5,1)
1       FORMAT(4X,'NAME OF INPUT FILE?'$)
        READ(5,2) FYLE
2       FORMAT(6A)
        WRITE(5,3)
3       FORMAT(4X,'NAME OF OUTPUT FILE?'$)
        READ(5,2) FYLEN
        OPEN(UNIT=1,FILE=FYLE,STATUS='OLD')
        OPEN(UNIT=2,FILE=FYLEN,STATUS='NEW')
        WRITE(5,8)
8       FORMAT(4X,'CATCHMENT NO.?'$)
        READ(5,9)(TITLE(I),I=1,10)
9       FORMAT(10A1)
        WRITE(5,10)
10      FORMAT(4X,'CATCHMENT AREA?'$)
        READ(5,*) CA
        WRITE(5,5)
5       FORMAT(4X,'SAMPLING INTERVAL?'$)
        READ(5,*) DLT
        WRITE(5,2000)
2000    FORMAT(4X,'DURATION OF UNIT HYDR. ?'$)
        READ(5,*) D
        WRITE(5,1000)
1000    FORMAT(4X,'DO YOU WANT TO CALIBRATE THE MODEL ?'$)
        READ(5,1001) IANS
1001    FORMAT(A4)
        IF(IANS.EQ.IYES) N2=1
        IF(N2.EQ.1) GO TO 1002
        WRITE(5,6)
6       FORMAT(4X,'AVERAGE VALUE OF N?'$)
        READ(5,*)  AN
        WRITE(5,7)
7       FORMAT(4X,'AVERAGE VALUE OF K?'$)
        READ(5,*) AK
1002    WRITE(5,111)
111     FORMAT(4X,'HOW MANY STORMS HAS TO BE ANALYSED?'$)
        READ(5,*) NST
        READ(1,*) CB
        DO 112 II=1,NST
C       READ NO OF STATIONS
        READ(1,*) NSTAT
```

```
C       READ THIES. WEIGHTS
        READ(1,*) (WT(I),I=1,NSTAT)
C       READ NO. OF RAIN FALL BLOCKS
        READ(1,*) NRAIN
C       READ RAIN FALL AT EACH STATIONS
        READ (1,*) ((RAIN(I,J),I=1,NRAIN),J=1,NSTAT)
        DO 1003 I=1,NRAIN
        EFR(I)=0.0
        DO 1003 J=1,NSTAT
1003    EFR(I)=EFR(I)+RAIN(I,J)*WT(J)
C       READ NO.  OF RUNOFF BLOCKS
        READ(1,*) NRUN
C       READ RUNOFF BLOCKS
        READ(1,*)(OBO(I),I=1,NRUN)
        WRITE(2,11)
11      FORMAT(20X,'UNIT HYDROGRAPH ANALYSIS- NASH MODEL')
        WRITE(2,12)
12      FORMAT(4X,100('*'))
        WRITE(2,13)
13      FORMAT(/)
        IF(N2.EQ.1) GO TO 1004
14      FORMAT(4X,'COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS
        1USING NASH MODELS,AVERGE PARAMETRS')
1004    WRITE(2,15) (TITLE(I),I=1,10)
15      FORMAT(4X,'CATCHMENT NO.-',4X,10A1)
        WRITE(2,16)CA
16      FORMAT(4X,'CATCHMENT AREA(SQ.KM)-',4X,F8.3)
        WRITE(2,3451) NSTAT
3451    FORMAT(4X,'NO. OF RAINGAUGE STATIONS=',2X,I3)
        WRITE(2,3452)
3452    FORMAT(10X,'WEIGHT OF EACH RAINGAUGE STATIONS')
        WRITE(2,3453)(WT(I),I=1,NSTAT)
3453    FORMAT(10F8.4)
        WRITE(2,3454) NRAIN
3454    FORMAT(4X,'NO. OF RAINFALL VALUES=',2X,I3)
        WRITE(2,4454)
4454    FORMAT(30X,'RAINFALL AT EACH STATIONS(MILLIMETR)')
        DO 3455 J=1,NSTAT
        K=J
        WRITE(2,3456) K
3456    FORMAT(4X,'STATION NO.=',2X,I3)
        WRITE(2,3457) (RAIN(I,J),I=1,NRAIN)
3457    FORMAT(10F8.2)
3455    CONTINUE
        WRITE(2,3458) NRUN
3458    FORMAT(4X,'NO. OF RUNOFF VALUES=',2X,I3)
        WRITE(2,3459)
3459    FORMAT(30X,'OBSERVED DISCHARGE HYDROGRAPH(CUMECS)')
        WRITE(2,3460) (OBO(I),I=1,NRUN)
3460    FORMAT(10F8.2)
```

```
      WRITE(2,4460)CB
4460  FORMAT(4X,'FLOW AT WHICH RECESSION START=',F8.2)
      WRITE(2,12)
      WRITE(2,3461)
3461  FORMAT(30X,'WEIGHTED RAINFALL VALUES(MILLIMETR)')
      WRITE(2,3462) (EFR(I),I=1,NRAIN)
3462  FORMAT(10F8.2)
      IF(N2.EQ.1) GO TO 1005
      WRITE(2,160) AN,AK
160   FORMAT(4X,'AVERAGE N-',4X,F8.3/4X,'AVERAGE K(HRS)-',4X,F8.3)
1005  TIME(1)=0.0
      DO 18 I=2,NRUN
      K=I-1
      TIME(I)=TIME(K)+DLT
18    CONTINUE
      SUM=0.0
      DO 2774 I=1,NRAIN
2774  SUM=SUM+EFR(I)*DLT
      NBEG=1
202   CALL RUNSEP(OBD,BFLO,ODSRO,NRUN,NBEG,TIME,CB)
      SDSRO=0.0
      DO 200I=NBEG,NRUN
200   SDSRO=SDSRO+ODSRO(I)
      SDSRO=SDSRO*DLT
      SDSRO=SDSRO*3.6/CA
      CALL RAINSP(EFR,SDSRO,DLT,EXR,NBEG,NRAIN,AINFR,SRX)
      IF(EXR(NBEG).GT. 0.0) GO TO 201
      NBEG=NBEG+1
      GO TO 202
201   NR=NRUN-NBEG+1
      WRITE(2,2020) NR
2020  FORMAT(4X,'NO. OF DIRECT SURFACE RUNOFF=',2X,I3)
      WRITE(2,205)
205   FORMAT(20X,'BASE FLOW (CUMECS)')
      WRITE(2,204) (BFLO(I),I=NBEG,NRUN)
      WRITE(2,203)
203   FORMAT(20X,'DIRECT SURFACE RUNOFF (CUMECS)')
      WRITE(2,204) (ODSRO(I),I=NBEG,NRUN)
      WRITE(2,2775) SUM
2775  FORMAT(4X,'TOTAL RAINFALL (MILLIMETER)=',2X,F10.3)
204   FORMAT(4X,10F8.3)
      WRITE(2,350) AINFR,SRX
350   FORMAT(4X,'INFILTRATION CAPACITY(MM/HR)-',4X,F8.3/4X,'TOTAL
     1 RAINFALL EXCESS(MM)-',4X,F8.3)
      NRN=NRAIN-NBEG+1
      DO 206 I=1,NRN
206   REXR(I)=EXR(I+NBEG-1)
      SUM2=0.0
      DO 2776 I=1,NRN
2776  SUM2=SUM2+REXR(I)*DLT
```

```
      RROC=SUM2/SUM
      WRITE(2,3899) RROC
3899  FORMAT(4X,'RUNOFF COEFFICIENT=',F8.4)
      DO 207 I=1,NR
207   ABFLO(I)=BFLO(I+NBFG-1)
      WRITE(2,208)
208   FORMAT(20X,'SEPERATED RAINFALL VALUES (MILLIMETER)',
      WRITE(2,209) (REXR(I),I=1,NRN)
209   FORMAT(4X,10F10.3)
      IF(N2.NE.1) GO TO 1006
      CALL MRUN(DSRO,NBEG,NRUN,DLT,QM1,QM2)
      CALL MRAIN(REXR,NRN,DLT,RM1,RM2)
      WRITE(2,1106) QM1,QM2,RM1,RM2
1106  FORMAT(4X,'FIRST MOMENT OF DSRO-',2X,F10.3/4X,'SECON. MOMENT OF
     1 DSRO-',2X,F10.3/4X,'FIRST MOMENT OF ERH-',2X,F10.3/4X,'SEC
     2OND MOMENT OF ERH-',2X,F10.3)
      ANK=QM1-RM1
      AK=((QM2-RM2-2*ANK*RM1)-ANK**2)/ANK
      AN=ANK/AK
      WRITE(2,1007)AN,AK
1007  FORMAT(4X,'VALUE OF N-',2X,F8.3/4X,'VALUE OF K(HRS)-',2X,F8.3)
1006  CALL DUHGAM(UH,NR,AN,AK,D,IER)
      CALL GAMMA(AN,GAMN,IER)
      DTIME=0.0
      DO 7687 I=1,NR
      DTIME=DTIME+DLT
      EXP1=EXP(-DTIME/AK)
      EXP2=(DTIME/AK)**(AN-1.0)
      EXP3=1.0/(AK*GAMN)
      UIR1(I)=EXP3*EXP1*EXP2
7687  UIR(I)=0.277*CA*UIR1(I)
      S7=0.0
      DO 7688 I=1,NR
      S7=S7+UIR1(I)
7688  CONTINUE
      WRITE(2,7689)
7689  FORMAT(10X,'I.U.H. ORDINATES(CUMECS)')
      WRITE(2,7690) (UIR(I),I=1,NR)
7690  FORMAT(4X,10F8.3)
      WRITE(2,7691) S7
7691  FORMAT(4X,'SUM OF IUH=',F12.5)
      DO 7692 I=1,NR
7692  UIRR(I)=UIR(I)
      CALL RANK(UIR,NR)
      DO 7693 I=1,NR
      IF(UIR(NR).NE.UIRR(I)) GO TO 7693
      JJ=I
      GO TO 7694
7693  CONTINUE
7694  WRITE(2,7695) UIR(NR),JJ
```

```
7695  FORMAT(4X,'I.U.H. PEAK=',2X,F10.3,/,4X,'I.U.H. TIME TO P
     1EAK=',2X,I3)
      SUMI=0.0
      DO 17 I=1,NR
      UR(I)=UH(I)*DLT
      SUMI=SUMI+UR(I)
17    CONTINUE
      WRITE(2,23)SUMI
23    FORMAT(10X,'AREA OF UH=',F12.5)
      DO 24 I=1,NR
24    UHS(I)=.277*CA*UH(I)
      WRITE(2,345)
345   FORMAT(20X,'UNIT HYDROGRAPH ORDINATES(CUMECS)')
      WRITE(2,346) (UHS(I),I=1,NR)
346   FORMAT(4X,10F8.3)
      DO 2874 I=1,NRN
2874  REXR(I)=0.2778*CA*REXR(I)
      CALL CONVOL(CDSRO,UH,REXR,NR)
      DO 26 I=1,NR
      K=I+NBEG
26    COMPD(K)=CDSRO(I)+BFLO(K)
      DO 308 I=1,NBEG
308   COMPD(I)=OBD(I)
      IF(N2.NE.1) WRITE(2,14)
      IF(N2.EQ.1) WRITE(2,1119)
      DO 2987 I=1,NRUN
      K=I
      IF(NBEG.LE.K) CCDSRO(I)=0.0
      IF(K.LE.NBEG) GO TO 2987
      CCDSRO(I)=CDSRO(I-NBEG)
2987  CONTINUE
      DO 2988 I=1,NRUN
      K=I
      IF(K.LT.NBEG) BBFLO(I)=OBD(I)
      IF(K.LT.NBEG) GO TO 2988
      BBFLO(I)=ABFLO(I-NBEG+1)
2988  CONTINUE
      WRITE(2,13)
      WRITE(2,12)
1119  FORMAT(4X,'COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS
     1 USING ACTUAL PARAMETRES')
      WRITE(2,27)
27    FORMAT(4X,'ORDINATE NO.',4X,'OBSERVED DISCHARGE',4X,'BASE F
     1LOW',4X,'DIRECT SURFACE RUNOFF',4X,'COMPUTED DISCHARGE')
      WRITE(2,12)
      DO 28 I=1,NRUN
      K=I
      WRITE(2,29) K,OBD(I),BBFLO(I),CCDSRO(I),COMPD(I)
29    FORMAT(4X,I3,15X,F7.1,15X,F7.1,15X,F7.1,15X,F7.1)
28    CONTINUE
```

```
      DO 600 I=1,NR
600   UHH(I)=UHS(I)
      CALL RANK(UHS,NR)
      DO 601 I=1,NR
      IF(UHS(NR).NE.UHH(I)) GO TO 601
      K=I
      GO TO 703
601   CONTINUE
703   WRITE(2,602) UHS(NR),K
602   FORMAT(4X,'U.H. PEAK(M**3/S)=',2X,F5.0/
     14X,'U.H. TIME TO PEAK  (HRS)=',2X,I2)
      S2=0.0
      DO 6835 I=1,NRUN
6835  S2=S2+OBD(I)
      ANRUN=NRUN
      SMEAN=S2/ANRUN
      S3=0.0
      S4=0.0
      DO 6836 I=1,NRUN
      S3=S3+(OBD(I)-SMEAN)**2
6836  S4=S4+(OBD(I)-COMPD(I))**2
      EFF=((S3-S4)/S3)*100.0
      WRITE(2,6837) EFF
6837  FORMAT(4X,'EFFICIENCY OF THE MODEL=',F10.2)
      DO 603 I=1,NRUN
      OOBD(I)=OBD(I)
603   CCOMPD(I)=COMPD(I)
      CALL RANK(OBD,NRUN)
      CALL RANK(COMPD,NRUN)
      DO 604 I=1,NRUN
      IF(OBD(NRUN).NE.OOBD(I)) GO TO 604
      J=I-1
      GO TO 701
604   CONTINUE
701   WRITE(2,605) OBD(NRUN),J
605   FORMAT(4X,'OBS. PEAK (M**3/S)=',2X,F7.1/4X,
     1'OBSERVED TIME TO PEAK (HRS)=',2X,I2)
      DO 606 I=1,NRUN
      IF(COMPD(NRUN).NE.CCOMPD(I)) GO TO606
      L=I-1
      GO TO 702
606   CONTINUE
702   WRITE(2,607) COMPD(NRUN),L
607   FORMAT(4X,'COMPUTED PEAK (M**3/S)=',2X,F7.1/4X,
     1'COMPUTED TIME TO PEAK (HRS)=',2X,I2)
      CALL ERROR(OOBD,CCOMPD,NRUN,STE,ABE,ABPE)
      WRITE(2,30) STE,ABE,ABPE
30    FORMAT(4X,'AVERAGE STANDARD ERROR=',2X,F8.3/4X,'AVREAGE AB
     1SOLUTE ERROR=',2X,F8.3/4X,'AVERAGE PERCENTAGE ABSOLUTE ERROR
     2=',2X,F8.3)
```

```
      PEPEAK=(ABS(OBD(NRUN)-COMPD(NRUN))/OBD(NRUN))*100
      AJ=J
      AL=L
      PETPEAK=(ABS(AJ-AL)/AJ)*100.0
      WRITE(2,6838) PEPEAK,PETPEAK
6838  FORMAT(4X,'PERCENTAGE ABSOLUTE ERROR IN PEAK=',F10.2,/,
     14X,'PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK=',F10.2)
      WRITE(2,13)
      DO 6839 I=1,NRUN
6839  REXR(I)=0.0
112   CONTINUE
      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      STOP
      END
C     ***************************************************************
      SUBROUTINE RAINSP(EEFR,SSDSRO,DDLT,EEXR,NNBEG,NNRAIN,AAINFR
     1,SSRX)
      DIMENSION EEFR(50),EEXR(50),RXS(50)
      AAINFR=0.0
15    NN=0
      SSRX=0.0
      DO 150 I=NNBEG,NNRAIN
      RXS(I)=EEFR(I)-AAINFR*DDLT
      IF(RXS(I).LE.0.0) GO TO 140
      EEXR(I)=RXS(I)
      NN=NN+DDLT
      GO TO145
140   EEXR(I)=0.0
145   SSRX=SSRX+EEXR(I)
150   CONTINUE
      IF((ABS(SSDSRO-SSRX))/(SSDSRO)-0.0001)20,20,35
35    AINF1=(SSRX-SSDSRO)/NN
      AAINFR=AAINFR+AINF1
      GO TO 15
20    CONTINUE
      RETURN
      END
C     ***************************************************************
      SUBROUTINE GAMMA(X,GAM,IER)
      IER=999
      IF(X.LT.0.0) RETURN
      IER=0.0
      IF(X.LE.20.0) GO TO 10
      Y=1./(X*X)
      P=(0.77783067E-3*Y-0.277765545E-2)*Y+0.8333333309E-1
      P=P/X
      GAM=(X-0.5)*ALOG(X)-X+0.9189385+P
      GAM=EXP(GAM)
      RETURN
```

```
10      Y=AINT(X)
        N=Y-2.
        Y=X-Y
        GAM=(((0.1082985985E-1*Y-0.3427052255E-2)*Y+0.77549276E-1)
        1*Y)
        GAM=(((GAM+0.8017824769E-1)*Y+0.4121029027)*Y+0.4227663678)*Y
        GAM=GAM+1.000000199
        T1=1.0
        YP2=Y+2.0
        IF(N) 40,70,60
40      CONTINUE
C  NEGATIVE N
        N=IABS(N)
        DO 45 I=1,N
45      T1=T1*(YP2-I)
        T1=1.0/T1
        GO TO 70
60      CONTINUE
C  POSITIVE N
        N=N-1
        DO 65 I=0,N
65      T1=T1*(YP2+I)
70      GAM=GAM*T1
        RETURN
        END
C       ******************************************************************
        SUBROUTINE CONVOL(QEST,UHH,REX,NRR)
        DIMENSION QEST(100),UHH(100),REX(50)
        DO 20 I=1,NRR
        SUM=0.0
        DO 10 J=1,I
        KK=I-J+1
10      SUM=SUM+UHH(J)*REX(KK)
20      QEST(I)=SUM
        RETURN
        END
C       ******************************************************************
        SUBROUTINE ERROR(OBSQ,COMPQ,N,SE,AE,APE)
        DIMENSION OBSQ(50),COMPQ(50)
        SUM1=0.0
        AN=N
        DO 10 I=1,N
10      SUM1=SUM1+(COMPQ(I)-OBSQ(I))**2
        SUM1=SUM1/AN
        SE=SQRT(SUM1)
        SUM2=0.0
        SUM3=0.0
        DO 20 I=1,N
        SUM2=SUM2+ABS(COMPQ(I)-OBSQ(I))
        SUM3=SUM3+(ABS(COMPQ(I)-OBSQ(I))/OBSQ(I))
```

```
20    CONTINUE
      SUM2=SUM2/AN
      AE=SUM2
      SUM3=(SUM3/AN)*100
      APE=SUM3
      RETURN
      END
C     ************************************************************
C     THIS SUBROUTINE GIVES RANK TO ANY VECTOR COLUMN IN DESCENDIND
      SUBROUTINE RANK(Y,N)
      DIMENSION Y(50)
      N1=N-1
      DO 3 I=1,N1
      K=N-I
      DO 3 J=1,K
      IF(Y(J)-Y(J+1))3,3,2
2     SAVE=Y(J)
      Y(J)=Y(J+1)
      Y(J+1)=SAVE
3     CONTINUE
      RETURN
      END
C     ************************************************************
C     THIS SUBROUTINE GIVES FIRST AND SECOND MOMENTS OF DSRO
      SUBROUTINE MRUN(DSRO,NR,N,DELT,DM1,DM2)
      DIMENSION DSRO(50),SUM(50),TIME(50)
      DO 10 I=NB,N
10    SUM(I)=(DSRO(I)+DSRO(I+1))/2.0
      AK=0.0
      DO 11 I=NR,N
      TIME(I)=AK+DELT/2
      AK=AK+DELT
11    CONTINUE
      S1=0.0
      S2=0.0
      S3=0.0
      DO 12 I=NR,N
      S1=S1+SUM(I)
      S2=S2+SUM(I)*TIME(I)
      S3=S3+SUM(I)*TIME(I)*TIME(I)
12    CONTINUE
      DM1=S2/S1
      DM2=S3/S1
      RETURN
      END
C     ************************************************************
C     THIS SUBROUTINE GIVES FIRST AND SECOND MOMENT OF EX. RAIN
      SUBROUTINE MRAIN(REX,N,DELT,DR1,DR2)
      DIMENSION REX(50),TIME(50)
      AK=0.0
```

```
      DO 10 I=1,N
      TIME(I)=AK+DELT/2
      AK=AK+DELT
10    CONTINUE
      S1=0.0
      S2=0.0
      S3=0.0
      DO 11 I=1,N
      S1=S1+REX(I)
      S2=S2+REX(I)*TIME(I)
      S3=S3+REX(I)*TIME(I)*TIME(I)
11    CONTINUE
      DR1=S2/S1
      DR2=S3/S1
      RETURN
      END
C     ************************************************************
      SUBROUTINE DUHGAM(DUH,NDUH,PN,PK,D,IER)
C     CALCULATE A D- PERIOD UNIT HYDROGRAPH FOR A GAMMA FUNCTION IUH
      DIMENSION DUH(NDUH)
      CALL GAMMA(PN,GAM,IER)
      IF(IER.NE.0) STOP 770
      T1=1.0/GAM
      IF(D.GT.0.0) GO TO 100
      T1=T1/PK
      DUH(1)=0.0
      DELTA=D/PK
      T2=DELTA
      PN1=PN-1.0
      DO 10 I=2,NDUH
      DUH(I)=T1*EXP(T2)*ABS(T2)**(PN1)
10    T2=T2+DELTA
      GO TO 200
100   DELTA=D/PK
      DUH1=0.0
      T2=DELTA
      DO 20 I=1,NDUH
      CALL ICGAMA(PN,T2,GAMI,IER)
      DUH2=GAMI
      DUH(I)=(DUH2-DUH1)/D
      DUH1=DUH2
20    T2=T2+DELTA
200   RETURN
      END
C     ************************************************************
      SUBROUTINE ICGAMA(A,X,GAMI,IER)
C     CALCULATES THE INCOMPLETE GAMMA FUNCTION
      IER=999
      IF(X.LE.0.0) RETURN
      NEND=10
```

```
      T=0.0
      J=NEND
      DO 10 I=1,NEND
      AJ=J
      T=(AJ-A)/(1.0+AJ/(X+T))
      J=J-1
10    CONTINUE
      T=1.0/(X+T)
      GAMI=EXP(-X)*X**A*T
      CALL GAMMA(A,GAM,IER)
      IF(IER.NE.0) STOP 777
      GAMI=1.0-GAMI/GAM
      IER=0
      RETURN
      END
C     ***************************************************************
      SUBROUTINE RUNSEP(Q,BF,DRO,NNRUN,NNBEG,TTIME,CB)
      DIMENSION Q(50),BF(50),DRO(50),TTIME(50)
      DO 50 I=NNBEG,NNRUN
      IF(Q(I).EQ.CB.AND.Q(I+1).LT.CB) GO TO 60
      IF(Q(I).EQ.CB.AND.Q(I+1).EQ.CB) GO TO 60
50    CONTINUE
60    MRUN=I
      Q(MRUN)=CB
      TTIME(MRUN)=TTIME(I)
      DO 10 I=NNBEG,MRUN
      DLT=TTIME(I)-TTIME(NNBEG)
      BF(I)=Q(NNBEG)+(Q(MRUN)-Q(NNBEG))*DLT/(TTIME(MRUN)-TTIME(NNBE
     1G))
      IF(Q(I)-BF(I)) 20,20,15
20    DRO(I)=0.0
      GO TO 10
15    DRO(I)=Q(I)-BF(I)
10    CONTINUE
      IF(MRUN.EQ.NNRUN) GO TO 80
      DO 70 I=(MRUN+1),NNRUN
      BF(I)=Q(I)
70    DRO(I)=0.0
80    RETURN
      END
```

F. EXAMPLE APPLICATION

a. Test input for option-I - The input data required to run the programme for option-I are supplied as follows:

i) Information supplied through terminal:

NAME OF INPUT FILE ? TEST.DAT

NAME OF OUTPUT FILE ? OUT1.DAT

CATCHMENT NO.? 807/1

CATCHMENT AREA ? 823.62

SAMPLING INTERVAL ? 1

DURATION OF UNIT HYDROGRAPH? 1

DO YOU WANT TO CALIBRATE THE MODEL? YES

HOW MANY STORMS HAS TO BE ANALYSED? 1

ii) Information supplied through the file TEST.DAT:

```
105
5
0.156 0.181 0.272 0.171 0.220
7
0  0  0  8  7 10  0
0 11 13  9  0  0 12
2  0  6 15  3  9  1
0  0 25 10  8  0  0
0  0 14 21  5.5 11 1.5
20
 55  55  60  65 142 285 355 370 430 440
285 260 210 170 150 132 120 115 105 100
```

b. Test input for option-II - The input data required to run the programme for option-II are supplied as follows:

i) Information supplied through terminal:

```
NAME OF INPUT FILE ?                  TEST.DAT
NAME OF OUTPUT FILE ?                 OUT2.DAT
CATCHMENT NO. ?                       807/1
CATCHMENT AREA ?                      823.62
SAMPLING INTERVAL ?                   1
DURATION OF UNIT HYDROGRAPH ?         1
DO YOU WANT TO CALIBRATE THE MODEL ? NO
AVERAGE VALUE OF N ?                  3.96
AVERAGE VALUE OF K ?                  1.41
HOW MANY STORMS HAS TO BE ANALYSED? 1
```

ii) Information supplied through the file TEST.DAT:

```
105
5
0.156  0.181  .272  0.171  0.220
7
0   0   0   8   7   10   0
0   11  13  9   0   0    12
2   0   6   15  3   9    1
0   0   25  10  8   0    0
0   0   14  21  5.5 11   1.5
20
55  55  60  65  142  285  355  370  430  440
285 260 210 170 150  132  120  115  105  100
```

c. Test Output for Option-I

```
               UNIT HYDROGRAPH ANALYSIS- NASH MODEL
*********************************************************************************************

 CATCHMENT NO.-     S07/1
 CATCHMENT AREA(SQ.KM)-     823.620
 NO. OF RAINGAUGE STATIONS=    5
      WEIGHT OF EACH RAINGAUGE STATIONS
0.1560  0.1810  0.2720  0.1710  0.2200
 NO. OF RAINFALL VALUES=    7
                             RAINFALL AT EACH STATIONS(MILLIMETR)
 STATION NO.=     1
 0.00    0.00    0.00    0.00    7.00   10.00    0.00
 STATION NO.=     2
 0.00   11.00   13.00    9.00    0.00    0.00   12.00
 STATION NO.=     3
 2.00    0.00    6.00   15.00    3.00    9.00    1.00
 STATION NO.=     4
 0.00    0.00   25.00   10.00    0.00    0.00    0.00
 STATION NO.=     5
 0.00    0.00   14.00   21.00    5.50   11.00    1.50
 NO. OF RUNOFF VALUES=   20
                             OBSERVED DISCHARGE HYDROGRAPH(CUMECS)
 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
 FLOW AT WHICH RECESSION STARTS=  105.00
*********************************************************************************************
                             WEIGHTED RAINFALL VALUES(MILLIMETR)
 0.54    1.99   11.34   13.29    4.49    6.43    2.77
 NO. OF DIRECT SURFACE RUNOFF=   18
                    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
                    DIRECT SURFACE RUNOFF (CUMECS)
    0.000   2.188  76.375 216.563 283.750 275.938 353.125 360.313 202.500 174.688
  121.875  79.063  56.250  35.438  20.625  12.813   0.000   0.000
 TOTAL RAINFALL (MILLIMETER)=       40.850
 INFILTRATION CAPACITY(MM/HR)-        7.305
 TOTAL RAINFALL EXCESS(MM)-        10.016
 RUNOFF COEFFICIENT=  0.2452
                    SEPERATED RAINFALL VALUES (MILLIMETER)
     4.035     5.982     0.000     0.000     0.000
 FIRST MOMENT OF DSRO-        6.527
 SECON. MOMENT OF DSRO-       50.192
 FIRST MOMENT OF ERH-        1.097
 SECOND MOMENT OF ERH-        1.444
 VALUE OF N-      4.015
 VALUE OF K(HRS)-      1.352
     I.U.H. ORDINATES(CUMECS)
   3.300  20.453  33.156  37.683  35.254  29.160  22.160  15.824  10.775   7.068
```

4.497 2.791 1.696 1.013 0.593 0.345 0.198 0.112

SUM OF IUH= 0.99974

I.U.H. PEAK= 37.68262

I.U.H. TIME TO PEAK= . 4

AREA OF UH= 0.99916

UNIT HYDROGRAPH ORDINATES(CUMECS)

1.537 12.584 27.394 36.114 36.914 32.382 25.654 18.899 13.184 8.816

5.699 3.583 2.202 1.327 0.786 0.459 0.265 0.151

COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHS USING ACTUAL PARAMETRES

****

ORDINATE NO.	OBSERVED DISCHARGE	BASE FLOW	DIRECT SURFACE RUNOFF	COMPUTED DISCHARGE
1	55.0	55.0	0.0	55.0
2	55.0	55.0	0.0	55.0
3	60.0	60.0	0.0	60.0
4	65.0	62.8	6.2	69.0
5	142.0	65.6	60.1	125.8
6	205.0	68.4	186.3	254.8
7	355.0	71.3	310.5	381.7
8	370.0	74.1	366.0	440.1
9	430.0	76.9	352.5	429.3
10	440.0	79.7	298.1	377.7
11	295.0	82.5	230.4	312.9
12	260.0	85.3	166.7	252.0
13	230.0	88.1	114.8	202.9
14	170.0	90.9	75.9	166.7
15	150.0	93.8	48.7	142.4
16	132.0	96.6	30.4	127.0
17	120.0	99.4	18.6	118.0
18	115.0	102.2	11.1	113.3
19	105.0	105.0	6.6	111.6
20	100.0	100.0	3.0	103.0

U.H. PEAK(M**3/S)= 37.

U.H. TIME TO PEAK (HRS)= 5

EFFICIENCY OF THE MODEL= 96.15

OBS. PEAK (M**3/S)= 440.0

OBSERVED TIME TO PEAK (HRS)= 9

COMPUTED PEAK (M**3/S)= 440.1

COMPUTED TIME TO PEAK (HRS)= 7

AVERAGE STANDARD ERROR= 24.228

AVERAGE ABSOLUTE ERROR= 14.149

AVERAGE PERCENTAGE ABSOLUTE ERROR= 5.459

PERCENTAGE ABSOLUTE ERROR IN PEAK= 0.01

PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK= 22.22

AREA OF UH= 0.99801

UNIT HYDROGRAPH ORDINATES(CUMECS)

1.493 11.800 25.960 34.613 35.952 32.139 25.997 19.580 13.979 9.574

6.343 4.090 2.578 1.594 0.970 0.582 0.345 0.202

COMPARISON OF OBSERVED AND COMPUTED HYDROGRAPHSUSING NASH MODELS;AVERGE PARAMETRS

****

ORDINATE NO.	OBSERVED DISCHARGE	BASE FLOW	DIRECT SURFACE RUNOFF	COMPUTED DISCHARGE
1	55.0	55.0	0.0	55.0
2	55.0	55.0	0.0	55.0
3	60.0	60.0	0.0	60.0
4	65.0	62.8	6.0	68.8
5	142.0	65.6	57.0	122.6
6	285.0	68.4	176.3	244.7
7	355.0	71.3	295.8	367.0
8	370.0	74.1	353.1	427.2
9	430.0	76.9	345.7	422.6
10	440.0	79.7	298.0	377.7
11	285.0	82.5	235.2	317.7
12	260.0	85.3	174.0	259.3
13	210.0	88.1	122.6	210.7
14	170.0	90.9	83.1	174.0
15	150.0	93.8	54.6	148.3
16	132.0	96.6	35.0	131.5
17	120.0	99.4	21.9	121.3
18	115.0	102.2	13.5	115.7
19	105.0	105.0	8.2	113.2
20	100.0	100.0	4.9	104.9

U.H. PEAK(M**3/S)= 36.

U.H. TIME TO PEAK (HRS)= 5

EFFICIENCY OF THE MODEL= 96.54

OBS. PEAK (M**3/S)= 440.0

OBSERVED TIME TO PEAK (HRS)= 9

COMPUTED PEAK (M**3/S)= 427.2

COMPUTED TIME TO PEAK (HRS)= 7

AVERAGE STANDARD ERROR= 22.960

AVERAGE ABSOLUTE ERROR= 12.802

AVERAGE PERCENTAGE ABSOLUTE ERROR= 4.972

PERCENTAGE ABSOLUTE ERROR IN PEAK= 2.92

PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK= 22.22

APPENDIX II

DETAILS OF COMPUTER PROGRAMME FOR NASH MODEL USING OPTIMIZATION

A. DESCRIPTION OF COMPUTER PROGRAMME

The computer programme CONTI .FOR is written in FORTRAN-IV language and run on VAX-11/780 system. The programme estimates the parameters of Nash model optimizing (minimising) the objective function, sum of the squares of differences between observed and computed direct surface runoff hydrograph ordinates, using Quasi Newton procedure. The programme also computes the discharge hydrograph and the values of the error functions. The variables used in the main programme are described below:

VARIABLE	DESCRIPTION
CA	Catchment area
DLT	Sampling interval
D	Unit hydrograph duration
AN	Parameter N for Nash model
AK	Parameter K for Nash model
NEV	No. of storms to be used for analysis
BBC	A vector containing the flow at recession point of observed hydrographs
NSTAT	Number of raingauge stations
NRAIN	Number of rainfall blocks observed at the raingauge

stations

WT	A vector of Thiessenweights for each raingauge stations
RAIN	Matrix of rainfall values at different raingauge stations
EFR	A vector containing average valuesof rainfall blocks
NRUN	Number of discharge hydrograph ordinates
OBD	A vector of discharge hydrograph
BFLO	A vector of base flow ordinates
REXR	A vector of excess rainfall blocks
XS	A real vector containing the input series for each event in series. Each series does not need padding with zeros and thus the total number of elements is the sum of the number of input values for each event
YS	A real vector containing the output series for each event in series
NDUH	Number of unit hydrograph ordinates
NXS	An integer vector containing the length of each individual excess rainfall blocks, in the same order as they appear in XS
NYS	An integer vector containing the lengths of each individual output series in the same order as they appear in YS
UHS	A real vector containing the unit hydrograph ordinates
CBFLO	A real vector containing the base flow values for each event in series

YPRED   A real vector containing the computed surface runoff for each event in series

STE   Average standard error

ABE   Average absolute error

ABPE   Average percentage absolute error

EFF   Efficiency of the model

PEPEAK   Percentage absolute error in peak

PETPEAK   Percentage absolute error in time to peak

The main programme calls various subroutines for the different intermediate calculations. The following subroutines are required to run the programme:

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

ii. SUBROUTINE RAINSP(EEFR,SSDSRO,DDLT,EEXR,NNBEG, NNRAIN,AAINFR , SRX)

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

This subroutine calls two subroutines:

a. SUBROUTINE ICGAMA(A,X, GAMI, IER)

b. SUBROUTINE GAMMA (X, GAM, IER)

iv. SUBROUTINE ERROR (OBSQ,COMPQ, N, SE, AE, APE)

v. SUBROUTINE RANK (Y, N)

vi. SUBROUTINE KER16M (XS, YS, NXS, NYS, NEV, P1,P2, NDUH, DUH, IER)

This subroutine calls:

SUBROUTINE OPTQN (X, N, FUNC, TOL, ITMAX, IPRT,IER)

The subroutine OPTQN calls the following subroutines:

a. SUBROUTINE UPDATE (HES, U, N, S1, IER)

b. SUBROUTINE TSOLV1 (AMAT, RHS, ANS, N, IER)

c. SUBROUTINE TSOLV2 (AMAT, RHS, ANS, N IER)

vii. SUBROUTINE CONVM (XSC, YPRED, NXSC, NYSC, NEVC, DUHC, NDUHC, NOYS)

Subroutines (i) to (v) have already been described in appendix-I. The purpose and the description of the variables used as arguments for other subroutines are given below:

vi. SUBROUTINE KER16M(XS, YS, NXS, NYS, NEV, P1, P2, NDUH, DUH, IER)

This subroutine transfers the final values of the parameters and the unit hydrograph ordinates to the main programme. The calling arguments are:

XS — A real vector containing the input series for each event in series

YS — A real vector containing the output series for each event in series

NXS — An integer vector containing the lengths of each individual input series in the same order as they appear in XS

NYS — An integer vector containing the lengths of each individual output series in the same order as they appear in YS

NEV — An integer indicating the number of separate input output events

P1 — Parameter N for Nash model

P2 — Parameter K for Nash model

NDUH — Number of unit hydrograph ordinates

DUH — A real vector containing the values of unit hydrograph ordinates

IER An integer set by this subroutine to indicate either a successful estimation or a failure. If IER = 0 then estimation was successful otherwise failure

Subroutine KER16M calls the subroutine OPTQN which estimates the optimised parameters N and K. The subroutine is of the form:

SUBROUTINE OPTQN (X,N,FUNC,TOL, ITMAX,IPRT,IER)

where the calling arguments are:

X A real vector containing the parameter values

N An integer indicating number of the parameters

FUNC Value of the objective function estimated from a function subroutine, FUNCTION F16M(XP) where XP is a real vector containing the parameter values

TOL Tolerance limit specified as 10^{-3} in the programme. If the absolute difference between old function value and new function value is less or equal to TOL, the programme uses it as a stopping criteria

ITMAX Number of iterations specified as 200 in the programme

IPRT Print control having some positive number specified as 10 in the programme

IER Indicates success if IER = 0

The subroutine calls the following three subroutines during the optimisation:

a. SUBROUTINE UPDATE (HES, U, N, S1, IER)

This subroutine updates symmetric positive definite Hessian matrix and stores in condensed form. The calling arguments of the subroutine are:

HES A real vector containing the elements of

Hessian matrix

U A working vector

N Number of parameters to be optimised

S1 A working real constant

IER Equal to zero for the success of the routine

b. SUBROUTINE TSOLV1 (MAT, RHS,ANS,N, IER)

This subroutine solves upper triangular set of simultaneous linear equations and stores the coefficient matrix in the condensed form by row. The calling arguments are:

MAT A real vector containing the elements of upper triangular matrix

RHS A real vector containing the elements of right hand side of the linear simultaneous equations

ANS A real vector containing the values of unknowns

N Number of unknowns

IER Equal to zero for the success of the routine

c. SUBROUTINE TSOLV2 (MAT, RHS, ANS, N ,IER)

This subroutine solves lower triangular system of equations and stored the coefficient matrix by column. The calling arguments are:

MAT A real vector containing the coefficient of lower triangular matrix

RHS A real vector containing the right hand sides of the linear simultaneous equations

ANS A real vector containing the values obtained for unknowns

N Number of unknowns

IER Equal to zero for the success of the routine

vii. SUBROUTINE CONVM (XSC, YPRED, NXSC, NYSC, NEVC, DUHC, NDUHC, NOYS)

This subroutine computes the direct surface runoff (output series) convoluting the excess rainfall (input series) of each event with the average unit hydrograph and also stores the computed direct surface runoff hydrograph of each event in series. The calling arguments are:

XSC A real vector containing the input series for each event in series

YPRED A real vector containing the computed direct surface runoff for each event in series

NXSC An integer vector containing the lengths of each individual input series in the same order as they appear in XSC

NYSC An integer vector containing the length of each individual output series in the same order as they appear in YPRED

NEVC An integer indicating the number fo separate input-output events

DUHC A real vector containing the unit hydrograph ordinates

NDUHC Number of unit hydrograph ordinates

NOYS An integer indicating total number of elements stored in real vector YPRED

B. INPUT SPECIFICATIONS

The input specifications for the programme is the same as for the programme NASH .FOR(see Appendix-I) except the initial values of N and K is to be supplied in free format through file in the beginning.

C. OUTPUT DESCRIPTIONS

The output file consists the following variables of the main programme in different specified format:

VARIABLE	FORMAT	DESCRIPTION
TITLE(I)	10A1	A vector of some numerical or alphabatical characters to be used as identification of the catchment
CA	F8.3	Catchment area (km^2)
ODSRO(I)	10F8.3	A vector containing direct surface runoff hydrograph (m^3/s)
BFLO(I)	10F8.3	A vector containing base flow ordinates (m^3/s)
AINFR	F8.3	Infiltration capacity (mm/hr)
SRX	F8.3	Total rainfall excess (mm)
REXR(I)	10F10.3	A vector containing separated rainfall values (mm)
NDUH	I4	Number of unit hydrograph ordinates

SUM1	F12.5	Area of unit hydrograph
UHS(I)	10F8.3	A real vector containing the unit hydrograph ordinates (m^3/s)
UHS(NDUH)	F5.0	U.H. peak (m^3/s)
K	I2	U.H. time to peak (hours)
III	I3	Event number
YPRED(I)	10F10.3	Computed direct surface runoff hydrograph (DSRO)
YSQ(I)	F7.1	Observed discharge (m^3/s)
YPREDQ(I)	F7.1	Computed discharge vector (m^3/s)
EFF	F10.2	Efficiency of the model
YSQ(L1)	F7.1	Observed peak (m^3/s)
J	I2	Observed time to peak (hours)
YPREDQ(L1)	F7.1	Computed peak (m^3/s)
L	I2	Computed time to peak (hours)
STE	F8.3	Average standard error
ABE	F8.3	Average absolute error
ABPE	F8.3	Average percentage absolute error
PEPEAK	F10.2	Percentage absolute error in peak
PETPEAK	F10.2	Percentage absolute error in time to peak

In addition to the above variables, the output file consists the intermediate steps of optimization calling the subroutine OPTQN with the arguments.

D. TEST DATA

Catchment number	807/1
Catchment area	823.62 km^2
Sampling interval	One hour
Duration of unit hydrograph	One hour
Initial value of N	3.00
Initial value of K	2.00
Number of raingauge stations	5
Thiessen weights of the stations	0.1560 0.1810 0.2720 0.1710 0.220
Number of rainfall values observed at each stations	7

Rainfall values at each stations (mm)

Hr.	Stn.1	Stn.2	Stn.3	Stn.4	Stn5
1	0	0	2	0	0
2	0	11	0	0	0
3	0	13	6	25	14
4	8	9	15	10	21
5	7	0	3	8	5.5
6	10	0	9	0	11
7	0	12	1	0	1.5

Flow at recession point	105 m^3/s
Number of discharge values	20
Discharge values (m^3/s)	55 55 60 65 142 285 355 370 430 440 285 260 210 170 150 132 120 115 105 100

E. COMPUTER PROGRAMME CONTI.FOR

```
      DIMENSION EXR(50),OBSRO(50),CBSRO(50),BFLO(50),ORD(50)
      DIMENSION COMPD(50),TITLE(50),TIME(50),UIR(50),UR(50)
      DIMENSION EFR(50),ABFLO(50),REXR(50),UHH(50),NRU(2000)
      DIMENSION OORD(50),CCOMPD(50),UHS(50),WT(50),RAIN(50,50)
     1,NXS(50),NYS(50),X(50),Y(50),XS(2000),YS(2000),CBFLO(2000),
     2YSQ(2000),YPRED(2000),YPREDU(2000),NNBEG(50),ANOUH(50)
     3,UH(200),BBC(50)
      CHARACTER *6 FYLE,FYLEN
      WRITE(5,1)
1     FORMAT(4X,'NAME OF INPUT FILE?'$)
      READ(5,2) FYLE
2     FORMAT(6A)
      WRITE(5,3)
3     FORMAT(4X,'NAME OF OUTPUT FILE?'$)
      READ(5,2) FYLEN
      OPEN(UNIT=1,FILE=FYLE,STATUS='OLD')
      OPEN(UNIT=2,FILE=FYLEN,STATUS='NEW')
      WRITE(5,8)
8     FORMAT(4X,'CATCHMENT NO.?'$)
      READ(5,9)(TITLE(I),I=1,10)
9     FORMAT(10A1)
      WRITE(5,10)
10    FORMAT(4X,'CATCHMENT AREA?'$)
      READ(5,*) CA
      WRITE(5,5)
5     FORMAT(4X,'SAMPLING INTERVAL?'$)
      READ(5,*) DLT
      WRITE(5,999)
999   FORMAT(4X,'UNIT HYDROGRAPH DURATION?'$)
      READ(5,*)D
      M1=0
      M2=0
      K1=1
      K2=1
      K3=1
      M3=0
      WRITE(5,111)
111   FORMAT(4X,'HOW MANY STORMS HAS TO BE ANALYSED?'$)
      READ(5,*) NEV
      READ(1,*) AN,AK
      DO 112 II=1,NEV
      III=II
      READ(1,*)BBC(II)
      WRITE(2,5855) III
5855  FORMAT(4X,'EXCESS RAIN AND DIR. SURF. RUNOFF DETAIL FOR
     1EVENT NO.-',I3)
C     READ NO OF STATIONS
      READ(1,*) NSTAT
C     READ THIES. WEIGHTS
      READ(1,*) (WT(I),I=1,NSTAT)
```

```
C       READ NO. OF RAIN FALL BLOCKS
        READ(1,*) NRAIN
C       READ RAIN FALL AT EACH STATIONS
        READ (1,*) ((RAIN(I,J),I=1,NRAIN),J=1,NSTAT)
        DO 1003 I=1,NRAIN
        EFR(I)=0.0
        DO 1003 J=1,NSTAT
1003    EFR(I)=EFR(I)+RAIN(I,J)*WT(J)
C       READ NO.  OF RUNOFF BLOCKS
        READ(1,*) NRUN
C       READ RUNOFF BLOCKS
        READ(1,*)(OBD(I),I=1,NRUN)
        WRITE(2,15) (TITLE(I),I=1,10)
15      FORMAT(4X,'CATCHMENT NO.-',4X,10A1)
        WRITE(2,16)CA
16      FORMAT(4X,'CATCHMENT AREA-',4X,F8.3)
        TIME(1)=0.0
        DO 18 I=2,NRUN
        K=I-1
        TIME(I)=TIME(K)+DLT
18      CONTINUE
        NBEG=1
        CB=RBC(II)
202     CALL RUNSEP(OBD,BFLO,ODSRO,NRUN,NBEG,TIME,CB)
        SDSRO=0.0
        DO 200I=NBEG,NRUN
200     SDSRO=SDSRO+ODSRO(I)
        SDSRO=SDSRO*DLT
        SDSRO=SDSRO*3.6/CA
        CALL RAINSP(EFR,SDSRO,DLT,EXR,NBEG,NRAIN,AINFR,SRX)
        IF(EXR(NBEG).GT. 0.0) GO TO 201
        NBEG=NBEG+1
        GO TO 202
201     WRITE(2,203)
203     FORMAT(20X,'DIRECT SURFACE RUNOFF (CUMECS)')
        WRITE(2,204) (ODSRO(I),I=NBEG,NRUN)
204     FORMAT(4X,10F8.3)
        WRITE(2,205)
205     FORMAT(20X,'BASE FLOW (CUMECS)')
        WRITE(2,204) (BFLO(I),I=NBEG,NRUN)
        WRITE(2,350) AINFR,SRX
350     FORMAT(4X,'INFILTRATION CAPACITY(MM/HR)-',4X,F8.3/4X,'TOTAL
        1 RAINFALL EXCESS(MM)-',4X,F8.3)
        NR=NRUN-NBEG+1
        NRN=NRAIN-NBEG+1
        DO 206 I=1,NRN
206     REXR(I)=EXR(I+NBEG-1)
        IF(NBEG .EQ.1) GO TO 6969
        DO 207 I=1,(NBEG-1)
207     BFLO(I)=OBD(I)
```

```
6969    WRITE(2,208)
208     FORMAT(20X,'SEPERATED RAINFALL VALUES (CUMECS)')
        WRITE(2,209) (REXR(I),I=1,NRN)
209     FORMAT(4X,10F10.3)
        NR1=NR-1
        NYS(II)=NR1
        DO 5006 I=1,NR1
        X(I)=0.0
5006    Y(I)=0.0
        DO 5001 I=1,NRN
5001    X(I)=REXR(I)
        DO 5002 I=1,NR1
5002    Y(I)=OOSRO(I+NBEG)*3.6/CA
        NXS(II)=NRN
        M1=M1+NXS(II)
        J=0
        DO 5003 I=K1,M1
        J=J+1
5003    XS(I)=X(J)
        M2=M2+NYS(II)
        K=0
        DO 5004 I=K2,M2
        K=K+1
5004    YS(I)=Y(K)
        M3=M3+NRUN
        L=0
        DO 5007 I=K3,M3
        L=L+1
5007    CBFLO(I)=BFLO(L)
        K1=M1+1
        NNBEG(II)=NBEG
        K2=M2+1
        K3=M3+1
        ANDUH(II)=NYS(II)
        NRU(II)=NRUN
112     CONTINUE
        CALL RANK(ANDUH,NEV)
        NDUH=ANDUH(NEV)
        WRITE(2,4956) NDUH
4956    FORMAT(4X,'NO. OF UNIT HYDROGAPH ORDINATES=',I4)
        CALL KER16M(XS,YS,NXS,NYS,NEV,AN,AK,NDUH,UH,IER)
        CALL DUHGAM(UH,NDUH,AN,AK,D,IER)
        CALL CONVM(XS,YPRED,NXS,NYS,NEV,UH,NDUH,NOYS).
        SUMI=0.0
        DO 17 I=1,NDUH
        UR(I)=UH(I)*DLT
        SUMI=SUMI+UR(I)
17      CONTINUE
        WRITE(2,23)SUMI
23      FORMAT(10X,'AREA OF UH=',F12.5)
```

```
      DO 24 I=1,NDUH
24    UHS(I)=.277*CA*UH(I)
      WRITE(2,345)
345   FORMAT(20X,'UNIT HYDROGRAPH ORDINATES')
      WRITE(2,346) (UHS(I),I=1,NDUH)
346   FORMAT(4X,10F8.3)
      DO 600 I=1,NDUH
600   UHH(I)=UHS(I)
      CALL RANK(UHS,NDUH)
      DO 601 I=1,NRUN
      IF(UHS(NDUH).NE.UHH(I)) GO TO 601
      K=I
      GO TO 703
601   CONTINUE
703   WRITE(2,602) UHS(NDUH),K
602   FORMAT(4X,'U.H. PEAK(M**3/S)=',2X,F5.0/
     14X,'U.H. TIME TO PEAK  (HRS)=',2X,I2)
      NRM=0
      K3=1
      MA=0
      K4=0
      K5=1
      DO 110 I=1,NOYS
      YS(I)=YS(I)*0.27778*CA
110   YPRED(I)=YPRED(I)*0.2777*CA
      DO 109 II=1,NEV
      III=II
      WRITE(2,115) III
115   FORMAT(4X,'EVENT NO.-',2X,I3)
      NRM=NRM+NYS(II)
      WRITE(2,2000)
2000  FORMAT(10X,'ESTIMATED DIRECT SURFACE RUNOFF')
      WRITE(2,2244) (YPRED(I),I=K3,NRM)
2244  FORMAT(4X,10F10.3)
      WRITE(2,114)
114   FORMAT(15X,'COMPARISON OF OBSERVED AND SIMULATED HYDROGRA
     1PH')
      WRITE(2,116)
116   FORMAT(4X,'NO.',10X,'OBSERVED DSRO',10X,'COMPD DSRO')
      K4=K4+NNBEG(II)
      K6=NNBEG(II)
      DO 117 I=K3,NRM
      K4=K4+1
      K6=K6+1
      IF(K6.GT.NRU(II)) GO TO 117
      YPREDQ(K6)=YPRED(I)+CBFLO(K4)
      YSQ(K6)=YS(I)+CBFLO(K4)
117   CONTINUE
      NBEGN=NNBEG(II)
      MBEGN=K5+NBEGN-1
```

```
      K7=0
      DO 118 I=K5,MREGN
      K7=K7+1
      YSQ(K7)=CBFLO(I)
118   YPREDQ(K7)=CBFLO(I)
      M3=M3+NRU(II)
      L1=NRU(II)
      DO 121 I=1,L1
      KL=I
      WRITE(2,122) KL,YSQ(I),YPREDQ(I)
122   FORMAT(4X,I3,15X,F7.1,15X,F7.1)
121   CONTINUE
      S2=0.0
      DO 6835 I=1,L1
6835  S2=S2+YSQ(I)
      ANRUN=L1
      SMEAN=S2/ANRUN
      S3=0.0
      S4=0.0
      DO 6836 I=1,L1
      S3=S3+(YSQ(I)-SMEAN)**2
6836  S4=S4+(YSQ(I)-YPREDQ(I))**2
      EFF=((S3-S4)/S3)*100.0
      WRITE(2,6837) EFF
6837  FORMAT(4X,'EFFICIENCY OF THE MODEL=',F10.2)
      DO 603 I=1,L1
      OOBQ(I)=YSQ(I)
603   CCOMPQ(I)=YPREDQ(I)
      CALL RANK(YSQ,L1)
      CALL RANK(YPREDQ,L1)
      DO 604 I=1,L1
      IF(YSQ(L1).NE.OOBQ(I)) GO TO 604
      J=I-1
      GO TO 701
604   CONTINUE
701   WRITE(2,605) YSQ(L1),J
605   FORMAT(4X,'OBS. PEAK (M**3/S)=',2X,F7.1/4X,
     1'OBSERVED TIME TO PEAK (HRS)=',2X,I2)
      DO 606 I=1,L1
      IF(YPREDQ(L1).NE.CCOMPQ(I)) GO TO606
      L=I-1
      GO TO 702
606   CONTINUE
702   WRITE(2,607) YPREDQ(L1),L
607   FORMAT(4X,'COMPUTED PEAK (M**3/S)=',2X,F7.1/4X,
     1'COMPUTED TIME TO PEAK (HRS)=',2X,I2)
      CALL ERROR(OOBQ,CCOMPQ,L1,STE,ABE,ABPE)
      WRITE(2,30) STE,ABE,ABPE
30    FORMAT(4X,'AVERAGE STANDARD ERROR=',2X,F8.3/4X,'AVREAGE AB
     1SOLUTE ERROR=',2X,F8.3/4X,'AVERAGE PERCENTAGE ABSOLUTE ERROR
```

```
      2=',2X,F8.3)
      PEPEAK=(ABS(YSQ(L1)-YPREDQ(L1))/YSQ(L1))*100
      AJ=J
      AL=L
      PETPEAK=(ABS(AJ-AL)/AJ)*100.0
      WRITE(2,6838) PEPEAK,PETPEAK
6838  FORMAT(4X,'PERCENTAGE ABSOLUTE ERROR IN PEAK=',F10.2,/,
     14X,'PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK=',F10.2)
      K3=NRM+1
      K4=M3
      K5=M3+1
109   CONTINUE
      STOP
      END
C     ************************************************************
      SUBROUTINE RAINSP(EEFR,SSDSRO,DDLT,EEXR,NNBEG,NNRAIN,AAINFR
     1,SSRX)
      DIMENSION EEFR(50),EEXR(50),RXS(50)
      AAINFR=0.0
15    NN=0
      SSRX=0.0
      DO 150 I=NNBEG,NNRAIN
      RXS(I)=EEFR(I)-AAINFR*DDLT
      IF(RXS(I).LE.0.0) GO TO 140
      EEXR(I)=RXS(I)
      NN=NN+DDLT
      GO TO145
140   EEXR(I)=0.0
145   SSRX=SSRX+EEXR(I)
150   CONTINUE
      IF((ABS(SSDSRO-SSRX))/(SSDSRO)-0.01)20,20,35
35    AINF1=(SSRX-SSDSRO)/NN
      AAINFR=AAINFR+AINF1
      GO TO 15
20    CONTINUE
      RETURN
      END
C     ************************************************************
      SUBROUTINE KEN16M(XS,YS,NXS,NYS,NEV,P1,P2,NDUH,DUH,IER)
      EXTERNAL F16M
      DIMENSION XS(1),YS(1),NXS(NEV),NYS(NEV),DUH(NDUH),P(2)
      COMMON/K16M/ XSC(2000),YSC(2000),NXSC(20),NYSC(20),NEVC,
     1 DUHC(200),NDUHC,NOYS
      N1=0
      NOYS=0
      DO 10 I=1,NEV
      IT=NXS(I)
      NXSC(I)=IT
      N1=N1+IT
      IT=NYS(I)
```

```
      NYSC(I)=IT
   10 NOYS=NOYS+IT
      IF(NOYS.LT.N1) STOP 771
      DO 20 I=1,N1
      XSC(I)=XS(I)
   20 YSC(I)=YS(I)
      IF(NOYS.EQ.N1) GOTO 40
      IT=N1+1
      DO 30 I=IT,NOYS
   30 YSC(I)=YS(I)
   40 NEVC=NEV
      NDUHC=NDUH
      P(1)=P1
      P(2)=P2
      NP=2
      TOL=1.0E-3
      ITMAX=200
      IPRT=10
      CALL OPTGN(P,NP,F16M,TOL,ITMAX,IPRT,IER)
      DO 50 I=1,NDUH
   50 DUH(I)=DUHC(I)
      P1=P(1)
      P2=P(2)
   90 RETURN
      END
C     ***************************************************************
      FUNCTION F16M(XP)
      DIMENSION XP(2),YPRED(2000)
      COMMON/K16M/ XSC(2000),YSC(2000),NXSC(20),NYSC(20),NEVC,
     1DUHC(200),NDUHC,NOYS
      DOUBLE PRECISION SUM
      F16M=1.0E32
      D=1.0
      IF(XP(1).LE.1.0E-7.OR.XP(2).LE.1.0E-7) GOTO 20
      CALL DUHGAM(DUHC,NDUHC,XP(1),XP(2),0,IER)
      IF(IER.NE.0) STOP 551
      CALL CONVM(XSC,YPRED,NXSC,NYSC,NEVC,DUHC,NDUHC,NOYS)
      SUM=0.0D0
      DO 10 I=1,NOYS
      TEMP=(YPRED(I)-YSC(I))
   10 SUM=SUM+TEMP*TEMP
      F16M=SUM
   20 RETURN
      END
C     ***************************************************************
      SUBROUTINE CONVM(XSC,YPRED,NXSC,NYSC,NEVC,DUHC,NDUHC,NOYS)
      DIMENSION  XSC(2000),YSC(2000),NXSC(20),NYSC(20),
     1 DUHC(200)
      DIMENSION EXR(2000),COMP(2000),YPRED(2000)
      N1=0
```

```
      N2=0
      K1=1
      K2=1
      DO 1 II=1,NEVC
      N1=N1+NXSC(II)
      N2=N2+NYSC(II)
      L=0
      L1=0
      DO 10 I=1,N2
10    EXR(I)=0.0
      DO 2 I=K1,N1
      L=L+1
2     EXR(L)=XSC(I)
      DO 3 I=K2,N2
3     L1=L1+1
      DO 11 I=1,N2
11.   COMP(I)=0.0
      DO 4 I=1,L1
      SUM=0.0
      DO 5 J=1,I
      KK=I-J+1
5     SUM=SUM+DUHC(J)*EXR(KK)
4     COMP(I)=SUM
      DO 6 I=1,L1
      KK1=K2+I-1
6     YPRED(KK1)=COMP(I)
      K1=N1+1
      K2=N2+1
1     CONTINUE
      NOYS=KK1
      RETURN
      END
C     ***************************************************************
      SUBROUTINE OPTUM(X,N,FUNC,TOL,ITMAX,IPRT,IER)
      DIMENSION X(1),HES(210),GRAD(20),WORK(20),P(20),Y(20),
      1 GRAD0(20)
      DOUBLE PRECISION SUM,S2
      LOGICAL FOUND
      IER=999
      IF(N.GT.20) GO TO 400
      M=N*(N+1)/2
      IF(M.GT.210) GO TO 400
      IER=99
      TOL1=TOL
      TOL2=TOL
      TOL3=TOL*10.0
      STPMAX=1.0E20
      N1=N+1
      DELTA=1.0E-5
      STEP=1.0
```

```
      IF(IPRT.LE.0) GO TO 7301
      WRITE(2,800) N,TOL,(I,X(I),I=1,N)
800   FORMAT(/' OPTON CALLED WITH ARGUMENTS'/
     1' NO. OF PARAMETRS : ',I4/
     2' TOLERANCE        : ',F16.5/
     3' INITIAL PARAMETERS '//
     420(' ',I5,F12.5/))
7301  CONTINUE
      F2=FUNC(X)
      IRET=1
      GOTO 7102
7109  CONTINUE
      IT=1
      DO 10 I=1,M
10    HES(I)=0.0
      INDX=1
      DO 20 I=1,N
      HES(INDX)=1.0
20    INDX=INDX+N1-I
110   IT=IT+1
      IF(IT.GT.ITMAX) GO TO 400
      CALL TSOLV2(HES,GRAD,WORK,N,IER)
      IF(IER.NE.0) GO TO 400
      INDX=1
      DO 7308 I=1,N
      WORK(I)=WORK(I)/HES(INDX)
7308  INDX=INDX+N1-I
      CALL TSOLV1(HES,WORK,P,N,IER)
      IF(IER.NE.0) GOTO 400
      IF(IPRT.LE.0) GO TO 7302
      WRITE(2,500)IT,(I,GRAD(I),P(I),I=1,N)
500   FORMAT(/' ITERATION NO. :',I5/
     120(' ',I5,2E15.6/))
7302  CONTINUE
      ITL=0
      DX=STEP
      ALFA=0.0
      FOLD=F2
      FOUND=.FALSE.
60    ALFA=ALFA+DX
      ITL=ITL+1
      IF(ITL.GT.ITMAX) GO TO 410
      DO 30 I=1,N
30    WORK(I)=X(I)+ALFA*P(I)
      FNEW=FUNC(WORK)
      IF(FOLD-FNEW) 40,50,50
50    FOLD=FNEW
      FOUND=.TRUE.
      DX=DX*2.0
      GO TO 60
```

```
40      ALFA=ALFA-DX
        DX=-0.5*DX
        IF(ABS(DX).GT.TOL1.OR.FOLD.GE.F2) GO TO 60
410     IF(.NOT.FOUND) ALFA=1.0E-5
        IF(IPRT.LE.0) GO TO 7303
        WRITE(2,700) ITL,F2,FOLD
700     FORMAT(/' LINE SEARCH COMPLETED '/
       1' LINE ITERATION NO. 1',I5/
       2' OLD FUNCTION VALUE 1',F15.6/
       3' NEW FUNCTION VALUE 1',E15.6)
7303    CONTINUE
        F2=FOLD
        STPMAX=0.0
        DO 70 I=1,N
        TEMP=ALFA*P(I)
        STPMAX=AMAX1(STPMAX,ABS(TEMP))
70      X(I)=X(I)+TEMP
        IF(IPRT.LE.0) GOTO 7304
        WRITE(2,7104)
7104    FORMAT(' CURRENT SOLUTION'/)
        DO 75 I=1,N
75      WRITE(2,7105) I,X(I)
7105    FORMAT(' ',I5,F12.6)
7304    CONTINUE
        GMAX=0.0
        IRET=2
        GO TO 7102
7103    CONTINUE
        DO 80 I=1,N
80      GMAX=AMAX1(GMAX,ABS(GRAD(I)))
        IF(IPRT.LE.0) GO TO 7305
        WRITE(2,1100) STPMAX,GMAX
1100    FORMAT(' STPMAX,GMAX ',2E20.6)
7305    CONTINUE
        IF(STPMAX.LT.TOL2.AND.GMAX.LT.TOL3) GO TO 300
        S1=1.0/S1
        IF(S2.EQ.0.00) GO TO 300
        IF(ALFA.EQ.0.00) GO TO 300
        S2=1.0/(S2*ALFA)
        IF(IPRT.LE.0) GO TO 7410
        WRITE(2,7405) S1,S2
7405    FORMAT(' PRE UPDATED HESSIAN'/' MULTIPLIERS ',2E16.6)
        WRITE(2,7406)
7406    FORMAT(' VECTORS ')
        DO 7407 I=1,N
7407    WRITE(2,7408) I,GRADO(I),Y(I)
7408    FORMAT(' ',I5,2F12.6)
        DO 7409 I=1,M
7409    WRITE(2,7403)I,HES(I)
7410    CONTINUE
```

```
      CALL UPDATE(HES,GRADO,N,S1,IER)
      IF(IER.NE.0) GO TO 400
      CALL UPDATE(HES,Y,N,S2,IER)
      IF(IER.NE.0) GO TO 400
      INDX=1
      HESMAX=0.001
      DO 7501 I=1,N
      IF(HES(INDX).LT.HESMAX) GO TO 7502
      HESMAX=HES(INDX)
      GO TO 7501
7502  CONTINUE
      IF(HES(INDX).GT.DELTA) GO TO 7501
      HES(INDX)=HESMAX
7501  INDX=INDX+N1-I
      IF(IPRT.LE.0) GO TO 110
      WRITE(2,7401)
7401  FORMAT('  UPDATED HESSIAN')
      DO 7402 I=1,M
7402  WRITE(2,7403)I,HES(I)
7403  FORMAT(' ',I5,F15.6)
      GO TO 110
300   IER=0
400   RETURN
7102  CONTINUE
      S1=0.0
      S2=0.0
      DO 7101 I=1,N
      DX=AMAX1(ABS(0.00001*X(I)),1.E-15)
      X(I)=X(I)+DX
      F1=FUNC(X)
      X(I)=X(I)-DX
      IF(STPMAX.GT.TOL2) GO TO 7601
      X(I)=X(I)-DX
      F3=FUNC(X)
      X(I)=X(I)+DX
      SUM=F1-F3
      TEMP=SUM/(2.0*DX)
      GO TO 7603
7601  SUM=F2-F1
      TEMP=SUM/DX
7603  S1=S1-GRAD(I)*P(I)
      Y(I)=GRAD(I)-TEMP
      S2=S2+P(I)*Y(I)
      GRADO(I)=GRAD(I)
7101  GRAD(I)=TEMP
      GO TO(7109,7103),IRET
      END
C     ****************************************************************
      SUBROUTINE UPDATE(HES,U,N,S1,IER)
      DOUBLE PRECISION SUM
```

```
      DIMENSION HES(1),U(1),P(20)
      IER=999
      IF(N.GT.20) GO TO 700
      DELTA=1.0E-6
      N1=N+1
      TEMP=ABS(S1)
      DO 332 I=1,N
332   U(I)=U(I)*TEMP
      IF(S1.LE.0.0) GO TO 500
      INC=1
      T1=1.0
      DO 10 J=1,N
      PJ=U(J)
      P(J)=PJ
      HESINC=HES(INC)
      T2=T1+PJ*PJ/HESINC
      B=PJ/(HESINC*T2)
      HES(INC)=HESINC*T2/T1
      T1=T2
      ILIM=J+1
      IF(ILIM.GT.N) GO TO 10
      INC=INC+1
      DO 20 K=ILIM,N
      HESINC=HES(INC)
      UK=U(K)-PJ*HESINC
      U(K)=UK
      HES(INC)=HESINC+B*UK
20    INC=INC+1
10    CONTINUE
      GO TO 600
500   CONTINUE
      CALL ISOLV2(HES,U,P,N,IER)
      IF(IER.NE.0) GO TO 700
      INC=1
      SUM=0.0
      DO 30 I=1,N
      TEMP=P(I)
      SUM=SUM+TEMP*TEMP/HES(INC)
30    INC=INC+N1-I
      T1=1.0-SUM
      IF(T1.LT.DELTA)T1=DELTA
      IBAS=N*(N+1)/2
      J=N
40    PJ=P(J)
      INC=IBAS
      HESINC=HES(INC)
      T2=T1+PJ*PJ/HESINC
      B=-PJ/(HESINC*T1)
      U(J)=PJ
      TEMP=HESINC*T1/T2
```

```
      HES(INC)=TEMP
      T1=T2
      ILIM=J+1
      INC=INC+1
      IF(ILIM.GT.N) GO TO 60
      DO 50 K=ILIM,N
      TEMP=HES(INC)
      UK=U(K)
      HES(INC)=HES(INC)+B*UK
      U(K)=UK+PJ*TEMP
      INC=INC+1
50    CONTINUE
60    IBAS=IBAS+J-N-2
      J=J-1
      IF(J.GE.1) GO TO 40
600   IER=0
700   RETURN
      END
C     ************************************************************
      SUBROUTINE TSOLV1(AMAT,RHS,ANS,N,IER)
      DOUBLE PRECISION S
      DIMENSION AMAT(1),RHS(N),ANS(N)
      IER=999
      M=((N+1)*N)/2
      ANS(N)=RHS(N)
      M=M-1
      IN=N
10    IN=IN-1
      J=N
      S=0.0D0
20    S=S+ANS(J)*AMAT(M)
      M=M-1
      J=J-1
      IF(J.GT.IN) GO TO 20
      ANS(IN)=(RHS(IN)-S)
      M=M-1
      IF(IN.GT.1) GO TO 10
      IER=0
30    RETURN
      END
C     ************************************************************
      SUBROUTINE TSOLV2(AMAT,RHS,ANS,N,IER)
      DOUBLE PRECISION S
      DIMENSION AMAT(1),RHS(N),ANS(N)
      IER=999
      ANS(1)=RHS(1)
      DO 10 I=2,N
      S=0.0D0
      IN1=I
      LIM=I-1
```

```
      DO 20 J=1,LIM
      S=S+ANS(J)*AMAT(IN1)
20    IN1=IN1+N-J
10    ANS(I)=(RHS(I)-S)
      IER=0
30    RETURN
      END
C     ************************************************************
      SUBROUTINE GAMMA(X,GAM,IER)
      IER=999
      IF(X.LT.0.0) RETURN
      IER=0.0
      IF(X.LE.20.0) GO TO 10
      Y=1./(X*X)
      P=(0.77783067E-3*Y-0.277765545E-2)*Y+0.833333309E-1
      P=P/X
      GAM=(X-0.5)*ALOG(X)-X+0.9189385+P
      GAM=EXP(GAM)
      RETURN
10    Y=AINT(X)
      N=Y-2.
      Y=X-Y
      GAM=(((0.1082985985E-1*Y-0.3427052255E-2)*Y+0.77549276E-1)
      1*Y)
      GAM=(((GAM+0.8017824769E-1)*Y+0.4121029027)*Y+0.4227665678)*Y
      GAM=GAM+1.000000199
      T1=1.0
      YP2=Y+2.0
      IF(N) 40,70,60
40    CONTINUE
C  NEGATIVE N
      N=IABS(N)
      DO 45 I=1,N
45    T1=T1*(YP2-I)
      T1=1.0/T1
      GO TO 70
60    CONTINUE
C  POSITIVE N
      N=N-1
      DO 65 I=0,N
65    T1=T1*(YP2+I)
70    GAM=GAM*T1
      RETURN
      END
C     ************************************************************
      SUBROUTINE DUHGAM(DUH,NDUH,PN,PK,D,IER)
C     CALCULATE A D- PERIOD UNIT HYDROGRAPH FOR A GAMMA FUNCTION IUH
      DIMENSION DUH(NDUH)
      CALL GAMMA(PN,GAM,IER)
      IF(IER.NE.0) STOP 770
```

```
      T1=1.0/GAM
      IF(D.GT.0.0) GO TO 100
      T1=T1/PK
      DUH(1)=0.0
      DELTA=D/PK
      T2=DELTA
      PN1=PN-1.0
      DO 10 I=2,NDUH
      DUH(I)=T1*EXP(T2)*ABS(T2)**(PN1)
10    T2=T2+DELTA
      GO TO 200
100   DELTA=D/PK
      DUH1=0.0
      T2=DELTA
      DO 20 I=1,NDUH
      CALL ICGAMA(PN,T2,GAMI,IER)
      DUH2=GAMI
      DUH(I)=(DUH2-DUH1)/D
      DUH1=DUH2
20    T2=T2+DELTA
200   RETURN
      END
C     ****************************************************************
      SUBROUTINE ICGAMA(A,X,GAMI,IER)
C     CALCULATES THE INCOMPLETE GAMMA FUNCTION
      IER=999
      IF(X.LE.0.0) RETURN
      NEND=10
      T=0.0
      J=NEND
      DO 10 I=1,NEND
      AJ=J
      T=(AJ-A)/(1.0+AJ/(X+T))
      J=J-1
10    CONTINUE
      T=1.0/(X+T)
      GAMI=EXP(-X)*X**A*T
      CALL GAMMA(A,GAM,IER)
      IF(IER.NE.0) STOP 777
      GAMI=1.0-GAMI/GAM
      IER=0
      RETURN
      END
C     ****************************************************************
      SUBROUTINE ERROR(OBSQ,COMPQ,N,SE,AE,APE)
      DIMENSION OBSQ(50),COMPQ(50)
      SUM1=0.0
      AN=N
      DO 10 I=1,N
10    SUM1=SUM1+(COMPQ(I)-OBSQ(I))**2
```

```
      SUM1=SUM1/AN
      SE=SQRT(SUM1)
      SUM2=0.0
      SUM3=0.0
      DO 20 I=1,N
      SUM2=SUM2+ABS(COMPQ(I)-OBSQ(I))
      SUM3=SUM3+(ABS(COMPQ(I)-OBSQ(I))/OBSQ(I))
20    CONTINUE
      SUM2=SUM2/AN
      AE=SUM2
      SUM3=(SUM3/AN)*100
      APE=SUM3
      RETURN
      END
C     ******************************************************
C     THIS SUBROUTINE GIVES RANK TO ANY VECTOR COLUMN IN DESCENDING
      SUBROUTINE RANK(Y,N)
      DIMENSION Y(50)
      N1=N-1
      DO 3 I=1,N1
      K=N-I
      DO 3 J=1,K
      IF(Y(J)-Y(J+1))3,3,2
2     SAVE=Y(J)
      Y(J)=Y(J+1)
      Y(J+1)=SAVE
3     CONTINUE
      RETURN
      END
C     ***************************************************************
      SUBROUTINE RUNSEP(Q,BF,DRO,NNRUN,NNBEG,TTIME,CB)
      DIMENSION Q(50),BF(50),DRO(50),TTIME(50)
      DO 50 I=NNBEG,NNRUN
      IF(Q(I).EQ.CB.AND.Q(I+1).LT.CB) GO TO 60
      IF(Q(I).EQ.CB.AND.Q(I+1).EQ.CB) GO TO 60
50    CONTINUE
60    MRUN=I
      Q(MRUN)=CB
      TTIME(MRUN)=TTIME(I)
      DO 10 I=NNBEG,MRUN
      DLT=TTIME(I)-TTIME(NNBEG)
      BF(I)=Q(NNBEG)+(Q(MRUN)-Q(NNBEG))*DLT/(TTIME(MRUN)-TTIME(NNBE
     1G))
      IF(Q(I)-BF(I)) 20,20,15
20    DRO(I)=0.0
      GO TO 10
15    DRO(I)=Q(I)-BF(I)
10    CONTINUE
      IF(MRUN.EQ.NNRUN) GO TO 80
      DO 70 I=(MRUN+1),NNRUN
      BF(I)=Q(I)
70    DRO(I)=0.0
80    RETURN
      END
```

F. EXAMPLE APPLICATION

a. Test Input- The input data required to run the programme are supplied as follows:

i) Information supplied through terminal:

NAME OF INPUT FILE ?	TEST1.DAT
NAME OF OUTPUT FILE ?	OUT3.DAT
CATCHMENT NO. ?	807/1
CATCHMENT AREA ?	823.62
SAMPLING INTERVAL ?	1
DURATION OF UNIT HYDROGRAPH	1

HOW MANY STORMS HAS TO BE ANALYSED? 1

ii) Information supplied through the file TEST1.DAT

```
3.0 2.0
105
5
0.156  0.181  0.272  0.171  0.220
7
0   0   0   8   7    10   0
0   11  13  9   0    0    12
2   0   6   15  3    9    1
0   0   25  10  8    0    0
0   0   14  21  5.5  11   1.5
20
55   55   60   65   142  285  355  370  430  440
285  260  210  170  150  132  120  115  105  100
```

b. Test Output

```
EXCESS RAIN AND DIR. SURF. RUNOFF DETAIL FOR EVENT NO.-  1
CATCHMENT NO.-     807/1
CATCHMENT AREA-      823.620
                 DIRECT SURFACE RUNOFF (CUMECS)
   0.000   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   0.000   0.000
                 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
                 SEPERATED RAINFALL VALUES (MILIMETRES)
     4.035      5.982      0.000      0.000      0.000
 NO. OF UNIT HYDROGRAPH ORDINATES=  17

OPTON CALLED WITH ARGUMENTS
NO. OF PARAMETRS :     2
TOLERANCE        :        0.10000E-02
INITIAL PARAMETERS

    1      3.00000
    2      2.00000


ITERATION NO. :     2
    1  -0.280142E+00  -0.280142E+00
    2  -0.718236E+00  -0.718236E+00


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    16
OLD FUNCTION VALUE :    0.326719E+00
NEW FUNCTION VALUE :    0.294809E+00
CURRENT SOLUTION

    1     2.972642
    2     1.979860
STPMAX,GMAX            0.701402E-01          0.287733E+00
PRE UPDATED HESSIAN
MULTIPLIERS      -0.168253E+01     0.155288E+02
VECTORS
    1    -0.280142    -0.567875
    2    -0.718236    -0.696616
    1    0.100000E+01
    2    0.000000E+00
    3    0.100000E+01
 UPDATED HESSIAN
    1    0.786323E+02
    2    0.120886E+01
    3    0.224369E+01
```

```
ITERATION NO. :    3
    1   0.287733E+00   0.202712E+00
    2  -0.216198E-01  -0.164661E+00


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    18
OLD FUNCTION VALUE :    0.294809E+00
NEW FUNCTION VALUE :    0.239812E+00
CURRENT SOLUTION

    1    3.279086
    2    1.680938
STPMAX,GMAX          0.306444E+00          0.553163E+00
PRE UPDATED HESSIAN
MULTIPLIERS     -0.161585E+02     0.101628E+02
VECTORS
    1    0.287733   -0.145794
    2   -0.021620   -0.574783
    1   0.786323E+02
    2   0.120886E+01
    3   0.224369E+01
 UPDATED HESSIAN
    1   0.794898E+02
    2   0.130597E+01
    3   0.156932E+02

ITERATION NO. :    4
    1   0.433527E+00   0.653637E-02
    2   0.553163E+00  -0.828899E-03


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    32
OLD FUNCTION VALUE :    0.239812E+00
NEW FUNCTION VALUE :    0.210221E+00
CURRENT SOLUTION

    1    3.435793
    2    1.661065
STPMAX,GMAX          0.156707E+00          0.378570E+00
PRE UPDATED HESSIAN
MULTIPLIERS     -0.421021E+03     0.138787E+02
VECTORS
    1    0.433527    0.577950
    2    0.553163    0.931733
    1   0.794898E+02
    2   0.130597E+01
    3   0.156932E+02
```

```
 UPDATED HESSIAN
    1   0.647003E+02
    2   0.164712E+01
    3   0.141227E+02

ITERATION NO. :     5
    1  -0.144423E+00   0.141760E-01
    2  -0.378570E+00  -0.996174E-02


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    22
OLD FUNCTION VALUE :    0.210221E+00
NEW FUNCTION VALUE :    0.199439E+00
CURRENT SOLUTION

    1     3.576667
    2     1.562071
STPMAX,GMAX          0.140874E+00          0.925318E-01
PRE UPDATED HESSIAN
MULTIPLIERS    -0.580092E+03    0.369630E+02
VECTORS
    1    -0.144423    -0.139007
    2    -0.378570    -0.471102
    1   0.647003E+02
    2   0.164712E+01
    3   0.141227E+02
 UPDATED HESSIAN
    1   0.790010E+02
    2   0.208004E+01
    3   0.679413E+02

ITERATION NO. :     6
    1  -0.541608E-02  -0.324634E-02
    2   0.925318E-01   0.152775E-02


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    34
OLD FUNCTION VALUE :    0.199439E+00
NEW FUNCTION VALUE :    0.196761E+00
CURRENT SOLUTION

    1     3.695000
    2     1.506382
STPMAX,GMAX          0.118333E+00          0.134531E+00
PRE UPDATED HESSIAN
MULTIPLIERS    -0.629135E+04   -0.422138E+02
VECTORS
    1    -0.005416    -0.093331
```

```
    2    0.092532    0.227063
    1   0.790010E+02
    2   0.208004E+01
    3   0.679413E+02
 UPDATED HESSIAN
    1   0.788165E+02
    2   0.212491E+01
    3   0.788165E+02

ITERATION NO. :     7
    1   0.879148E-01   0.977893E-02
    2  -0.134531E+00  -0.407710E-02


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    18
OLD FUNCTION VALUE :   0.196761E+00
NEW FUNCTION VALUE :   0.196478E+00
CURRENT SOLUTION

    1    3.733963
    2    1.490138
STPMAX,GMAX           0.389629E-01          0.128998E+00
PRE UPDATED HESSIAN
MULTIPLIERS    -0.710121E+03    0.150236E+03
VECTORS
    1    0.087915    0.168527
    2   -0.134531   -0.005533
    1   0.788165E+02
    2   0.212491E+01
    3   0.788165E+02
 UPDATED HESSIAN
    1   0.714372E+03
    2   0.216735E+00
    3   0.388975E+03

ITERATION NO. :     8
    1  -0.806123E-01  -0.507016E-04
    2  -0.128998E+00  -0.286719E-03


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    34
OLD FUNCTION VALUE :   0.196478E+00
NEW FUNCTION VALUE :   0.194658E+00
CURRENT SOLUTION

    1    3.736154
    2    1.504223
STPMAX,GMAX           0.140851E-01          0.721899E+00
```

```
PRE UPDATED HESSIAN
MULTIPLIERS    -0.243466E+05    0.111587F+04
VECTORS
    1   -0.080612   -0.165558
    2   -0.128998    0.092901
    1   0.714372E+03
    2   0.216735E+00
    3   0.388975E+03
 UPDATED HESSIAN
    1   0.346852E+05
    2  -0.554979E+00
    3   0.808232E+02

ITERATION NO. :    9
    1   0.849454E-01  -0.119753E-02
    2  -0.221899E+00  -0.216221E-02


 LINE SEARCH COMPLETED
LINE ITERATION NO. :    12
OLD FUNCTION VALUE :    0.194658E+00
NEW FUNCTION VALUE :    0.194656E+00
CURRENT SOLUTION

    1    3.736155
    2    1.503682
STPMAX,GMAX           0.540552E-03          0.376572E-01
PRE UPDATED HESSIAN
MULTIPLIERS    -0.264503E+04    0.875535E+04
VECTORS
    1    0.084945    0.087139
    2   -0.221899   -0.259557
    1   0.346852E+05
    2  -0.554979E+00
    3   0.808232E+02
 UPDATED HESSIAN
    1   0.616733E+06
    2  -0.284235E+01
    3   0.192368E+06

ITERATION NO. :   10
    1  -0.219360E-02   0.460724E-06
    2   0.376572E-01   0.163344E-06


 LINE SEARCH COMPLETED
LINE ITERATION NO. :  201
OLD FUNCTION VALUE :    0.194656E+00
NEW FUNCTION VALUE :    0.194656E+00
CURRENT SOLUTION
```

```
  1    3.736155
  2    1.503682
STPMAX,GMAX          0.000000E+00         0.376572E-01
       AREA OF UH=     0.99724
                 UNIT HYDROGRAPH ORDINATES (M**3/SEC)
   1.895  12.772  26.298  34.017  34.907  31.175  25.382  19.346  14.035   9.798
   6.633   4.379   2.832   1.799   1.126   0.695   0.424
 U.H. PEAK(M**3/S)=     35.
 U.H. TIME TO PEAK  (HRS)=   5
 EVENT NO.-    1
       ESTIMATED DIRECT SURFACE RUNOFF (M**3/SEC)
     7.666    63.074   182.957   295.290   345.175   335.416   289.607   230.457   172.778
    85.583    57.491    37.715    24.256    15.339     9.561     5.884
          COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH
```

NO.	OBSERVED HYDRO	COMPD HYDRO
1	55.0	55.0
2	55.0	55.0
3	60.0	60.0
4	65.0	70.5
5	142.0	128.6
6	285.0	251.4
7	355.0	366.5
8	370.0	419.2
9	430.0	412.3
10	440.0	369.3
11	285.0	313.0
12	260.0	258.1
13	210.0	211.9
14	170.0	176.5
15	150.0	151.2
16	132.0	134.3
17	120.0	123.6
18	115.0	117.5
19	105.0	114.6
20	100.0	105.9

```
 EFFICIENCY OF THE MODEL=      96.66
 OBS. PEAK (M**3/S)=     440.0
 OBSERVED TIME TO PEAK (HRS)=   9
 COMPUTED PEAK (M**3/S)=     419.2
 COMPUTED TIME TO PEAK (HRS)=   7
 AVERAGE STANDARD ERROR=     22.574
 AVREAGE ABSOLUTE ERROR=    13.253
 AVERAGE PERCENTAGE ABSOLUTE ERROR=      5.221
 PERCENTAGE ABSOLUTE ERROR IN PEAK=       4.72
 PECENTAGE ABSOLUTE ERROR IN TIME TO PEAK=      22.22
```