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RESERVOIR ROUTING WITH GRAPHICAL REPRESENTATION

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ABSTRACT

Reservoir routing is a phenomenon which takes care of the effect of flood wave entering a reservoir. It is required in the design of the capacity of spill-ways and other reservoir outlet structures and in the location and sizing of capacity of reservoirs to meet specific requirements.

In the present report, a generalised software RESR has been developed for reservoir routing which includes various methods of routing. The developed soft-ware can be further updated by adding subroutines for data processing etc. as per the requirements.

A Graphical package has been used for graphical representation of results.

1.0 INTRODUCTION

The analysis of problems such as flood forecasting, flood moderation, reservoir design and spillway design invariably includes flood routing. In these applications, two broad categories of routing can be recognised. These are reservoir routing and channel routing.

In reservoir routing the effect of flood wave entering a reservoir is studied. Knowing the volume-elevation characteristic of reservoir and the outflow elevation relationship for the spillways and other outlet structures in reservoir, the effect of a flood wave entering the reservoir is studied to predict the variations of reservoir elevation and outflow discharge with time. This form of routing is essential:

(i) in the design of the capacity of spillways and other reservoir outlet structures and

(ii) in the location and sizing of the capacity of reservoirs to meet specific requirements.

A variety of routing methods are available and they can be broadly classified into two categories : (i) Hydrologic routing and (ii) hydraulic routing. Hydrologic routing methods essentially employ the equation of continuity. Hydraulic methods, on the other hand, employ the continuity equation together with the equation of motion of unsteady flow.

Several methods have been developed for routing the floods in reservoirs. Each method possesses distinctive features that make it suitable for a particular application. The criteria used in selecting a particular method include data requirements, computational efficacy , accuracy of results and availability of code.

1.1 Aim of the Present Work

The aim of the present report is to describe and document a generalized software RESR which has been developed for reservoir routing computations. The user can optionally select any of the several available methods. The theory of each of these methods has been discussed. Preparation of input, execution of programme and interpretation of output have been described in the report.

2.0 RESERVOIR ROUTING

The passage of flood hydrograph through a reservoir is an unsteady flow phenomenon. The equation of continuity is used in all hydrologic routing methods as primary equation. According to this equation, the difference between the inflow and outflow is equal to the rate of change of storage, i.e.

$$I - Q = \frac{dS}{dt} \quad \ldots(1)$$

where I = inflow, Q = Outflow, S = Storage and t=time

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

$$\bar{I}\ \Delta t - \bar{Q}\ \Delta t = \Delta S \quad \ldots(2)$$

where $\bar{I}$ = average inflow, $\bar{Q}$ = average outflow and ΔS = change in storage, all over time Δt. Assuming

$$\bar{I} = (I_1 + I_2)/2, \quad \bar{Q} = (Q_1+Q_2)/2$$

$$\Delta S = S_2 - S_1$$

Where suffixes 1 and 2 denote the beginning and end of time interval Δt, equation (2) is written as

$$\left(\frac{I_1 + I_2}{2}\right) \Delta t - \left(\frac{Q_1 + Q_2}{2}\right) \Delta t = S_2 - S_1 \quad \ldots(3)$$

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

Equation (3) can be rearranged as:

$$\left(\frac{I_1 + I_2}{2}\right) \Delta t + \left(S_1 - \frac{Q_1 \Delta t}{2}\right) = \left(S_2 + \frac{Q_2 \Delta t}{2}\right) \quad ..(4)$$

The schematic representation of reservoir routing is given in figure 1.

Using the above basic equation, several methods for routing a flood wave through a reservoir have been developed, namely,

- The Mass Curve Method
- The Puls Method
- The Modified Puls Method
- The Wisler - Brater Method
- The Goodrich Method
- The Steinberg Method
- The Coefficient Method

A brief description of each of these methods follows:

2.1 The Mass Curve Method

This is one of the most versatile methods of reservoir routing, various versions of which include: (i) direct, (ii) trial and error, and (iii) graphical. Here the trial and error version is being described in detail.

For solution by trial and error method, equation (1) can be rewritten as

$$M_2 - (V_1 + \bar{Q} \Delta t) = S_2 \quad ...(5)$$

where, M is the mass (accumulated) inflow,

V is the accumulated mass outflow

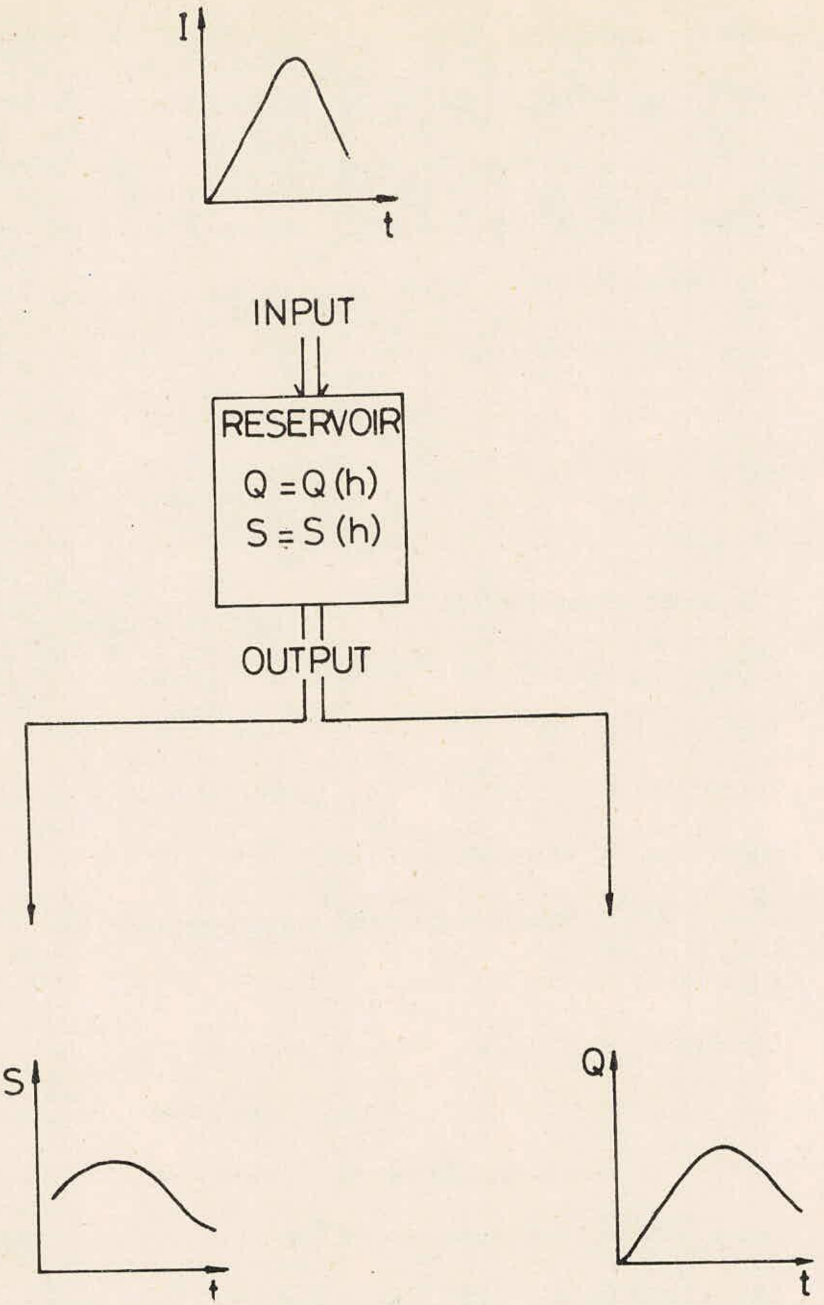

FIG. 1. SCHEMATIC REPRESENTATION OF RESERVOIR ROUTING

The input includes the mass inflow, whereas the output includes the mass outflow, outflow hydrograph and reservoir storage. A storage-discharge relationship, mass curve of inflow should be plotted before obtaining trial and error solution. Necessary adjustments are made to show zero storage at the beginning elevation and, correspondingly, spillway discharge is obtained. Now, following steps are involved in trial and error solution.

(a) A time is chosen and Δt is computed. Mass inflow is also computed.

(b) Mass outflow is assumed. As a guideline, it is a function of accumulated mass inflow.

(c) Reservoir storage is computed by deducting mass outflow from mass inflow.

(d) Now, instantaneous and average spillway discharges are calculated.

(e) Outflow for the time period Δt is computed by multiplying Δt with average discharge. Then, the mass outflow is computed.

(f) Now, computed mass outflow is compared with assumed mass outflow. If the two values agree within an acceptable degree of accuracy, then the routing is complete. If this agreement is not acceptable, then another mass outflow is assumed and the above procedure is repeated.

2.2 The Puls Method

In the Puls method, the continuity equation is expressed as

$$\left(\frac{I_1+I_2}{2}\right)\Delta t + \left(S_1 - \frac{Q_1}{2}\Delta t\right) = \left(S_2 + \frac{Q_2}{2}\Delta t\right) \qquad \ldots(6)$$

The computations are performed as follows. At the starting of flood routing, the initial storage and outflow discharge are known. In equation (6) all the terms in the left hand side are known at the beginning of time step Δt. Hence the value of the function $\left(S_2 + \frac{Q_2 \Delta t}{2}\right)$ at the end of the time step is calçulated by equation (6). Since the relation $S = S(h)$ and $Q = Q(h)$ are known, $\left(S + \frac{Q\,\Delta t}{2}\right)_2$ will enable one to determine the reservoir elevation and hence the discharge at the end of the time step. This procedure is repeated to cover the full inflow hydrograph.

2.3 The Modified Puls Method

This is also referred to as the Storage-Indication Method. This method represents equation (1) in finite difference form

$$S_2 - S_1 = (I_1+I_2)\frac{\Delta t}{2} - (Q_1+Q_2)\frac{\Delta t}{2} \qquad \ldots(7)$$

in which Q may incorporate controlled discharge Q_c as well as uncontrolled discharge Q_s,

$$Q = Q_c + Q_s$$

Separating the known quantities from the unknown ones and rearranging

$$(I_1+I_2)-(Q_{c_1}+Q_{c_2})+\left(\frac{2S_1}{\Delta t}-Q_{s_1}\right)=\frac{2S_2}{\Delta t}+Q_{s_2} \qquad \ldots(8)$$

The left side contains the known terms and the right side is unknown. The inflow hydrograph is known. Q_c is known and which may pass through the turbines, outlet works, or over the spillway. The uncontrolled discharge, Q_s, goes freely over the spillway. It depends upon the depth of flow over the spillway and spillway geometry. Further, the depth of flow over the spillway depends upon the level of water in the reservoir. Therefore,

$$S = S\,(Y)$$

$$Q_s = Q_s(Y)$$

where Y represents the water surface elevation. The right side of equation (8) can be written as

$$\frac{2S}{\Delta t} + Q = f(Y)$$

In order to utilize equation (8), the elevation storage and elevation - discharge relationship must be known. For simplicity Q_c is assumed to be negligible and Q can be taken to imply Q_s. Before routing, the curves of ($2S/\Delta t \pm Q$) versus Q are constructed. The routing is now very simple and can be performed using the above equation.

2.4 The Wisler -Brater Method

In this method, storage is expressed as a function of sum of inflow and outflow and storage curves for $I + Q$ versus $(2S/\Delta t) + I + Q$ are constructed. The basic equation of reservoir routing can be expressed as

$$\frac{2S_1}{\Delta t} + I_1 + 2I_2 - Q_1 = \frac{2S_2}{\Delta t} + I_2 + Q_2 \qquad ...(9)$$

In the above equation every term on left hand side is known for a given routing period and hence the right side can be computed. Then the value of $I_2 + Q_2$ can be read from the storage curves. Since, I_2 is known, Q_2 is obtained. This procedure is repeated for subsequent routing periods.

The above procedure can also be extended to the case where storage is a function of weighted sum of inflow and outflow.

2.5 The Goodrich Method

Goodrich expresses continuity equation as

$$I_1 + I_2 + \frac{2S_1}{\Delta t} - Q_1 = \frac{2S_2}{\Delta t} + Q_2 \qquad ...(10)$$

Goodrich method involves construction of a family of routing curves for $[(2S/\Delta t) \pm Q]$ against Q for various values of I. As all the terms on the left side of the above equation are known, the right side can be obtained for a routing period Δt. The value of Q_2 can now be read from the routing curves against $[(2S_2/\Delta t) + Q_2]$ and then S_2 can be computed. The routing can be carried out for subsequent time periods in the similar manner.

2.6 The Steinberg Method

The steinberg method expresses equation (1) as

$$(I_1+I_2-Q_1)\frac{\Delta t}{2} + S_1 = \frac{\Delta t}{2} Q_2 + S_2+K \qquad ...(11)$$

The term $K = S\ (Q\Delta t/2)$ is called the storage factor. Curves are plotted for storage factor which are termed as K-curves. The storage curves, showing storage as a function of inflow and outflow, are superimposed over K-curves. All left side terms of above equation are known and so the right side is obtained. Then Q_2 and S_2 are read from the superimposed curves. The routing is similarly carried out for subsequent time periods.

2.7 The Coefficient Method

The coefficient method represents the reservoir by a single conceptual storage element, where storage S is directly proportional to outflow Q,

$$S = K\,Q \qquad \ldots(12)$$

where K is a proportionality factor equal to the reciprocal of the slope of the storage curve that can be a constant or a variable function of outflow. If K is constant, then the reservoir is linear, otherwise the reservoir is non-linear.

For flood routing, a finite difference approximation is normally employed. Equation (1) and equation (2) can be combined and written as

$$K(Q_2-Q_1) = \frac{\Delta t}{2}(I_1 + I_2) - \frac{\Delta t}{2}(Q_1+Q_2)$$

Rearranging the terms,

$$Q_2 = Q_1+C(I_1-Q_1)+0.5C(I_2-I_1) \qquad \ldots(13)$$

in which

$$C = \frac{\Delta t}{K + 0.5\,\Delta t} \qquad \ldots(14)$$

If K is variable, then C can be derived and plotted as a function of Q. For each routing period, the appropriate value of C must be obtained corresponding to the outflow under consideration. Then, by using equation (13) flood routing can be performed.

2.8 General Comments

Selection of a proper routing time interval Δt in all flood routing problems is very important. Its value should be neither too long nor too short. If it is too long and exceeds the travel time through the reservoir, then the crest segment of outflow containing the peak discharge could pass through the reservoir between time intervals and could, therefore, not be computed. If on the other hand, it is too short, then it takes longer to perform flood routing. Further, Δt is assumed so short that I is approximately linear during it. As a guideline, Δt should be one-third to one-half the travel time through the reservoir. Furthermore, the routing interval Δt can be either variable or constant. However, it is more realistic to use a variable Δt, keeping it small for a large change in mass inflow and large for a small change therein.

The merits and demerits of different methods can be enumerated as below:

The routing operation performed by trial and error solution of the Mass Curve method is simple and easily done. This can be efficiently adapted to complex routing problems.

The Puls method and the Modified Puls method, both have two shortcomings. First, the assumption that the outflow begins at the same time as the inflow does imply that the inflow passes through the reservoir instantaneously regardless of its length. Second, it is difficult to choose an appropriate Δt since negative outflow occurs during recession whenever $\Delta t > 2S_2/Q_2$ or $Q_2/2 > S_2/\Delta t$. The former drawback is not a serious one if the ratio of T_t/T_m is less than or equal to 1/2, where T_m denotes time to peak of inflow hydrograph and T_t denotes travel time. T_t is defined as L/u, with L being, the length of the reach and u being average steady state velocity. The latter weakness can be circumvented by plotting discharge versus $[(2S/\Delta t)+Q]$ curve on a log-log paper and comparing the plot with the line of equal values. If the plotted values lie above the line of equal values, drawn figure must be abondoned and a new value of Δt must be selected. Further, negative outflow can be avoided usually by taking Δt less than Tm

Wisler-Brater method requires observed basin for routing computations and so this can best be simulated in controlled conditions. Due to this reason, its use is very much restricted for practical purposes.

The Steinberg method requires K-curves and their superimposition over storage curves, thereby, it involves a lot of graphical work before actual routing computations are carried out.

3.0 DATA REQUIREMENTS

For obtaining solution of a reservoir routing problem, following data have to be known:

(i) Storage volume VS elevation for the reservoir

(ii) Water surface elevation VS outflow and hence storage VS outflow discharge

(iii) Inflow hydrograph.

(iv) Initial values of storage, inflow and outflow

(v) For Coefficient method, the value of proportionality constant K, which is the reciprocal of the slope of the storage curve, is also needed.

4.0 DESCRIPTION OF SOFTWARE RESR

The developed software package RESR is written in FORTRAN-77 language. It has been developed on 16 bit IBM-compatible personal computer (PC/XT) (INTEL 8086) having a floating point/numeric co-processor (INTEL 8087).

4.1 Programme Description

Various methods have been grouped together in RESR and a separate code has been assigned to different methods of flood routing. The details of these are

Name of Method	Code No.
The Mass Curve Method	1
The Modified Puls Method	2
The Goodrich Method	3
The Coefficient Method	4

The main programme asks for the code of the method selected, input and output data files and reads the basic common input to different methods. The various sub-programs used are as follows:

(a) SUBROUTINE MASSTE

For trial and error solution by Mass Curve method

(b) SUBROUTINE PULS

For Puls Method of routing. The Modified Puls method is also included in this.

(c) SUBROUTINE GR

For Goodrich method of routing.

(d) SUBROUTINE CO

Routing computations by Coefficient method is done in this subroutine subprogram.

(e) SUBROUTINE GRAPHX

This subroutine draws inflow hydrograph and routed hydrograph.

(f) FUNCTION POL

This function subprogram is used for linear interpolation of values.

4.2 Flow Chart

The general flow diagram of programme RESR is shown in fig.2.

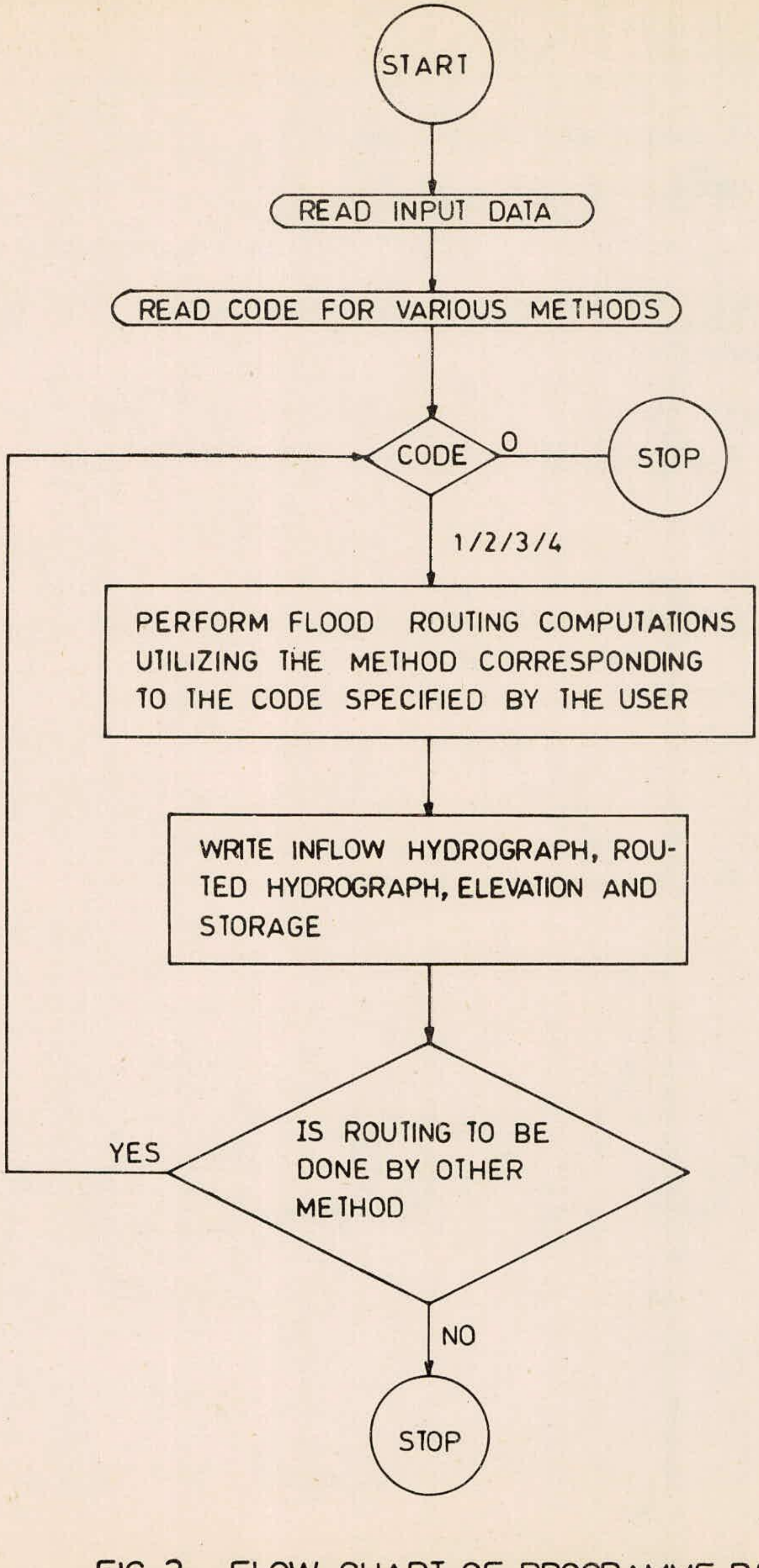

FIG. 2 - FLOW CHART OF PROGRAMME RESR

5.0 PREPARATION OF INPUT DATA FILE

Software package RESR is developed on the basis of the procedure explained in the foregoing section. The structure of a typical data file is as follows.

Programme requires following informations on monitor during execution.

	Possible response
1) PLEASE ENTER CODE	The code for a particular method should be entered.
2) INPUT FILE NAME ?	The name of input data file to be supplied.
3) OUTPUT FILE NAME ?	The output file name is to be supplied.
4) DO U WANT TO PLOT HYDRO-GRAPHS ON SCREEN ENTER (Y/N)	When the programme is executed, the user has the option to view the inflow and routed hydrographs on screen by typing Y, or else type N.
5) U HAVE ENTERED A WRONG STRING. WRITE AGAIN	If user has typed any letter except Y or N, then he is asked to type it again correctly.
6) WOULD YOU NOW LIKE TO TEST RUN ANOTHER OPTION PLEASE ENTER (Y/N)	When programme execution by one method is completed, the user has the option to run for other method by typing Y, or else N can be typed to terminate the programme execution.
7. U HAVE ENTERED A WRONG STRING. PL. WRITE AGAIN	If user, by mistake, has typed any letter except (Y/N), then this message will appear on monitor. Retype Y or N.

Actual data files for different methods have the following structure.

(1) For Mass Curve Method

Line	Variable Title	Format	Description
1	Title	A	Title of the problem
2	N	Free	No. of values in elevation -storage-outflow table
	NRT	Free	No. of periods for which routing is to be done
	FAC	Free	Factor by which inflows are to be multiplied.
	DT	Free	Time interval for computations in hrs.
3 to N+2	TA(I,1)	Free	Elevation values for reservoir
	TA(I,2)	Free	Storage values for reservoir
	TA(I,3)	Free	Outflow values for reservoir
N+2 to as required.	FIN(I)	Free	Inflow hydrograph values.

2) For Puls, Modified Puls and Goodrich Methods

The format is same as for the Mass Curve method except that it contains one more line for reading beginning elevation:

Next line	BEL	Free	Beginning elevation

If routing computations are to be performed for different elevations, more than one value of BEL may be given. If BEL value is -1, programme stops.

3) For Coefficient Method:

Line	Variable Title	Format	Description
1	Title	A	Title of the problem
2	K	Free	value of proportionality factor
	N	Free	No. of periods for which routing is to be performed.
	DT	Free	Time interval for computations in hrs.

5.1 Running RESR on PC

Software RESR can be executed on IBM-compatible personal computer using MICROSOFT compiler. After successful compilation and linking, .EXE version is created. The programme is then invoked by typing RESR followed by RETURN key.

6.0 CONCLUSION

A generalized software package for reservoir routing computations has been developed. The same is described here. The guidelines for programme usage alongwith sample computations are given in this report. General guidelines about selection of various parameters have also been given in the report.

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3. Chow, V.T.(1964), Handbook of Applied Hydrology, McGraw Hill, New York, NY.

4. Singh, Vijay P. (1988), Hydrologic Systems: Rainfall-Runoff Modelling, Vol.I, Prentice Hall, Englewood Cliffs, New Jersey 07632.

5. Microsoft FORTRAN Reference Manual

Listing of Programme RESR

```
      C         PROGRAM FOR RESERVOIR ROUTING
      CHARACTER*80 TITLE,CHAR*10,FIL*10
      DIMENSION OF(50),ELE(50),ST(50)
      COMMON /ONE/TA(50,4),N
      COMMON /TWO/FIN(50),NRT,FAC,DT
      COMMON /GRA/T(50),H1(50)
C     DEFINITION  N - No of values in elevation-storage-outflow table
C                                     TA(I,1)  TA(I,2)   TA(I,3)
C               NRT - No of periods for which routing is to be done
C                DT - Time interval of computations in hrs
C               FAC - Factor by which inflows are to be multiplied
C               FIN - Inflows to the reservoir
C               BEL - Beginning elevation

      WRITE (*,200)
200   FORMAT(25X,'RESERVOIR ROUTING PROGRAMME'/
     1       25X,'---------------------------')
232   WRITE(*,201)
201   FORMAT(///10X,'FOR  MASS  CURVE  METHOD OF ROUTING  ........  '
     1 'CODE IS ..1  '/10X,'FOR MODIFIED PULS METHOD OF ROUTING  '
     2 '........ CODE IS ..2  '/10X,'FOR    GOODRICH   METHOD OF '
     3 'ROUTING  ........ CODE IS ..3  '/10X,'FOR  COEFFICIENT '
     4 ' METHOD OF ROUTING  ........  CODE IS ..4  '//10X,
     5 'TO   RETURN   TO    MAIN   MENU  ........  ENTER'
     6 '   ..0  '/)
      WRITE(*,203)
203   FORMAT(//35X,'PLEASE ENTER CODE ...... '$)
      READ(*,*) ICODE
      IF(ICODE.EQ.0)STOP
      WRITE(*,2)
2     FORMAT(/10X,'INPUT  FILE NAME  ?   '$)
      READ(*,1)FIL
      OPEN(UNIT=1,FILE=FIL,STATUS='OLD')
      WRITE(*,3)
3     FORMAT(//10X,'OUTPUT FILE NAME  ?   '$)
      READ(*,1)FIL
      OPEN(UNIT=2,FILE=FIL,STATUS='NEW')
      IF(ICODE.EQ.4) GO TO 240
      READ(1,1) TITLE
      READ (1,*) N,NRT,FAC,DT
      READ (1,*) ((TA(I,J),J=1,3),I=1,N)
      READ (1,*) (FIN(I),I=1,NRT)
      DO 5 I=1,NRT
      T(I)=(I-1)*DT
      H1(I)=FIN(I)
5     CONTINUE
1     FORMAT(A)
      WRITE(2,1)TITLE
      IF(ICODE.EQ.1) CALL MASSTE
      IF(ICODE.EQ.2) CALL PULS
      IF(ICODE.EQ.3) CALL GR
240   IF(ICODE.EQ.4) CALL COEF
      WRITE(*,10)
10    FORMAT(///10X,'WOULD YOU NOW LIKE TO TEST RUN ANOTHER OPTION.'/
     1 10X'PLEASE ENTER (Y/N)........ '$)
```

```
235     CONTINUE
        READ(*,1) CHAR
        IF(CHAR.EQ.'Y') GO TO 232
        IF(CHAR.EQ.'N') STOP
        WRITE(*,12)
12      FORMAT(///10X,'U HAVE ENTERED A WRONG STRING.'/
     1         ,10X,'PL. WRITE AGAIN .... '$)
        GO TO 235
        END
C***   END OF MAIN PROGRAMME  ***




C*1*  -------------  ** MASS CURVE METHOD **  -------------------
C***  SUBROUTINE FOR RESERVOIR ROUTING BY TRIAL AND ERROR OPTION
C***  OF MASS CURVE METHOD.

        SUBROUTINE MASSTE
        DIMENSION FMIN(50),FCIN(50),AAO(50),SD(50),ST(50),OF(50),COF(50)
        COMMON /ONE/TA(50,4),N
        COMMON /TWO/FIN(50),NRT,FAC,DT
        COMMON /GRA/T(50),H1(50)
        write(2,5)
5       format(125(1h-)/1x,' time        ','    dt ','     mass  ',
     1  '        cumulative','      assumed     ','        reservoir',
     2  '     average  ','      outflow ','      cumulative'/1
     3  x,' accumulated','     (h)','       inflow ','        mass
     4  ,'     accumulated','       volume    ','        spillway ',
     5  '     for dt  ','       outflow    '/1x,' (h)       ',4x,
     6  '               m**3/s h ','     inflow       ','      outflow
     7  ,'     10**6 m**3','      discharge','      10**6 m**3',
     8  '    10**6 m**3 '/37x,' 10**6 m**3','      10**6 m**3',15x,
     9  '      m**3/s    '/125(1h-))
        DO 10 I=1,NRT
        FMIN(I)=(FIN(I)+FIN(I-1))*DT/2
        FCIN(I)=FCIN(I-1)+FMIN(I)
        AAO(I)=FCIN(I)*3600*0.2
10      CONTINUE
        TI=-DT
        DO 20 I=1,NRT
        IT=0
        TI=TI+DT
15      ST(I)=FCIN(I)*3600.0-AAO(I)
        IT=IT+1
        IF(ST(I).LT.0) ST(I)=0
        REL=POL(ST(I),2,3)
        SD(I)=(REL+SD(I-1))/2
        OF(I)=SD(I)*DT*3600
        COF(I)=OF(I)+COF(I-1)
        IF(IT.GT.80) GO TO 20
        IF(ABS(AAO(I)-COF(I)).LT.0.01*ST(I)) GO TO 20
        IF(COF(I).GT.AAO(I)) AAO(I)=AAO(I)+COF(I)*0.01
        IF(COF(I).LT.AAO(I)) AAO(I)=AAO(I)-COF(I)*0.01
        GO TO 15
```

```
20      WRITE(2,21)TI,DT,FMIN(I),FCIN(I)*3600./10**6,AAO(I)/10**6,
     1  ST(I)/10**6,SD(I),OF(I)/10**6,COF(I)/10**6
21      FORMAT(1X,F6.1,6X,F5.1,2(5X,F9.2),5(7X,F8.2))
        WRITE (2,22)
22      FORMAT(/125(1H-))
        WRITE(*,25)
25      FORMAT(//10X,' DO U WANT TO PLOT HYDROGRAPHS ON SCREEN '/
     1  10X,' ENTER( Y/N) ..... '$)
13      READ(*,1) CHAR
        IF(CHAR.EQ.'Y') GO TO 30
        IF(CHAR.EQ.'N') RETURN
        WRITE(*,12)
12      FORMAT(//10X,' U HAVE ENTERED A WRONG STRING.'/
     1  10X,' WRITE AGAIN .....'$)
        GO TO 13
30      CALL GRAPHX(NRT,SD)
1       FORMAT(A)
        RETURN
        END


C*1*  -------------   ** MODIFIED PULS METHOD **  -------------
C***  SUBROUTINE TO ROUT THE RESERVOIR BY  MODIFIED PULS METHOD.
C***  THIS ALSO INCLUDES PULS METHOD OF ROUTING.

        SUBROUTINE PULS
        DIMENSION OF(50),ELE(50),ST(50)
        COMMON /ONE/TA(50,4),N
        COMMON /TWO/FIN(50),NRT,FAC,DT
        COMMON /GRA/T(50),H1(50)
        WRITE(2,2)
2       FORMAT(5X,'!',46('-'),'!'/5X,'!',1X,'S. !',1X,'ELEVATION',3X,
     1  '!',3X,'STORAGE',3X,'!',3X,'OUTFLOW',3X,'!'/5X,'!',1X,'NO !',
     2  4X,'METER',4X,'!',2X,'E+06 M**3',2X,'!',5X,'CUMECS',2X,'!'/5X
     3  ,'!',46('-'),'!')
        DO 101 I=1,N
        WRITE(2,3) I,TA(I,1),TA(I,2),TA(I,3)
101     CONTINUE
3       FORMAT(5X,'!',1X,I2,1X,'!',3(2X,F9.3,2X,'!'))
        WRITE(2,4)
4       FORMAT(5X,'!',46('-'),'!'//)
        DT=DT*3600
        FAC=FAC*DT
        DO 102 I=1,N
        TA(I,2)=TA(I,2)*1.E+06
        TA(I,3)=TA(I,3)*DT
        TA(I,4) = TA(I,2)+TA(I,3)/2.
102     CONTINUE
111     READ (1,*) BEL
        IF(BEL.EQ.-1) THEN
        GO TO 13
        ENDIF
        WRITE(2,5) BEL
5       FORMAT(8X,'THE BEGINNING ELEVATION IS ',F9.3,'   METER'//)
        ELE(1)=BEL
        TS1=POL(BEL,1,2)
        ST(1)=TS1
```

```
      OF(1)=POL(BEL,1,3)
      FIN(1)=FIN(1)*FAC
      DO 103 I=1,NRT-1
      FIN(I+1)=FIN(I+1)*FAC
      ST2=(FIN(I)+FIN(I+1))/2.+TS1-OF(I)/2.
      OF(I+1)=POL(ST2,4,3)
      ELE(I+1)=POL(ST2,4,1)
      TS1=ST2-OF(I+1)/2.
      ST(I+1)=TS1
103   CONTINUE
      ST(NRT)=POL(ELE(NRT),1,2)
      WRITE(2,6)
6     FORMAT(5X,'!',56('-'),'!'/5X,'! S. !',3X,'INFLOW',3X,'!',2X,
     1 'OUTFLOW',3X,'!',1X,'ELEVATION',2X,'!',2X,'STORAGE',3X,'!',/
     2 5X,'! NO !',4X,'CUMECS',2X,'!',3X,'CUMECS',3X,'!',4X,'METER',
     3 3X,'!',1X,'E+06 M**3',2X,'!'/5X,'!',56('-'),'!')
      DO 104 I=1,NRT
      FIN(I)=FIN(I)/FAC
      OF(I)=OF(I)/DT
104   WRITE(2,7) I,FIN(I),OF(I),ELE(I),ST(I)/1.E+06
7     FORMAT(5X,'!',1X,I2,1X,'!',4(1X,F8.2,3X,'!'))
      WRITE(2,8)
8     FORMAT(5X,'!',56('-'),'!')
      GO TO 111
13    WRITE(*,25)
25    FORMAT(//10X,' DO U WANT TO PLOT HYDROGRAPHS ON SCREEN '/
     1 10X,' ENTER( Y/N) ..... '$)
14    READ(*,1) CHAR
      IF(CHAR.EQ.'Y') GO TO 30
      IF(CHAR.EQ.'N') RETURN
      WRITE(*,12)
12    FORMAT(//10X,' U HAVE ENTERED A WRONG STRING.'/
     1 10X,' WRITE AGAIN .....'$)
      GO TO 14
30    CALL GRAPHX(NRT,OF)
1     FORMAT(A)
      RETURN
      END


C*2*  -------------- ** THE GOODRICH METHOD ** ------------------
C***  THIS SUBROUTINE PERFORMS ROUTING BY GOODRICH METHOD.

      SUBROUTINE GR
      DIMENSION OF(50),ELE(50),ST(50)
      COMMON /ONE/TA(50,4),N
      COMMON /TWO/FIN(50),NRT,FAC,DT
      COMMON /GRA/T(50),H1(50)
      WRITE(2,2)
2     FORMAT(5X,'!',46('-'),'!'/5X,'!',1X,'S. !',1X,'ELEVATION',3X,
     1 '!',3X,'STORAGE',3X,'!',3X,'OUTFLOW',3X,'!'/5X,'!',1X,'NO !',
     2 4X,'METER',4X,'!',2X,'E+06 M**3',2X,'!',5X,'CUMECS',2X,'!'/5X
     3 ,'!',46('-'),'!')
      DO 101 I=1,N
      WRITE(2,3) I,TA(I,1),TA(I,2),TA(I,3)
101   CONTINUE
3     FORMAT(5X,'!',1X,I2,1X,'!',3(2X,F9.3,2X,'!'))
```

```
      WRITE(2,4)
4     FORMAT(5X,'!',46('-'),'!'//)
      DT=DT*3600.
      DO 105 I=1,NRT
105   FIN(I)=FIN(I)*FAC
      DO 102 I=1,N
      TA(I,2)=TA(I,2)*1.E+06/DT
      TA(I,4)=TA(I,3)+2.*TA(I,2)
102   CONTINUE
100   READ (1,*) BEL
      IF(BEL.EQ.-1) GO TO 13
      WRITE(2,5) BEL
5     FORMAT(8X,'THE BEGINNING ELEVATION IS ',F9.3,'  METER'//)
      ELE(1)=BEL
      TS1=POL(BEL,1,2)
      ST(1)=TS1
      OF(1)=POL(BEL,1,3)
      DO 103 I=1,NRT-1
      ST2=(FIN(I)+FIN(I+1))+2.*ST(I)-OF(I)
      OF(I+1)=POL(ST2,4,3)
      ELE(I+1)=POL(ST2,4,1)
      TS1=(ST2-OF(I+1))/2.
      ST(I+1)=TS1
103   CONTINUE
      ST(NRT)=POL(ELE(NRT),1,2)
      WRITE(2,6)
6     FORMAT(5X,'!',56('-'),'!'/5X,'! S. !',3X,'INFLOW',3X,'!',2X,
     1 'OUTFLOW',3X,'!',1X,'ELEVATION',2X,'!',2X,'STORAGE',3X,'!',/
     2 5X,'! NO !',4X,'CUMECS',2X,'!',3X,'CUMECS',3X,'!',4X,'METER',
     3 3X,'!',1X,'E+06 M**3',2X,'!'/5X,'!',56('-'),'!')
      DO 104 I=1,NRT
      WRITE(2,7) I,FIN(I),OF(I),ELE(I),ST(I)*DT/1.E+06
104   CONTINUE
7     FORMAT(5X,'!',1X,I2,1X,'!',4(1X,F8.2,3X,'!'))
      WRITE(2,8)
8     FORMAT(5X,'!',56('-'),'!')
      GO TO 100
13    WRITE(*,25)
25    FORMAT(//10X,' DO U WANT TO PLOT HYDROGRAPHS ON SCREEN '/
     1 10X,' ENTER( Y/N) ..... '$)
14    READ(*,1) CHAR
      IF(CHAR.EQ.'Y') GO TO 30
      IF(CHAR.EQ.'N') RETURN
      WRITE(*,12)
12    FORMAT(//10X,' U HAVE ENTERED A WRONG STRING.'/
     1 10X,' WRITE AGAIN .....'$)
      GO TO 14
30    CALL GRAPHX(NRT,OF)
1     FORMAT(A)
      RETURN
      END


C*3* ------------- ** THE COEFFICIENT METHOD ** ----------------
C*** SUBROUTINE TO PERFORM ROUTING BY COEFFICIENT METHOD.

      SUBROUTINE COEF
```

```
      CHARACTER*80 TITLE
      COMMON /GRA/T(50),H1(50)
      DIMENSION Q(50),FIN(50)
      READ(1,1)TITLE
      WRITE(2,9)
      WRITE(2,1)TITLE
      READ(1,*)K,N,DT
      READ(1,*)(FIN(I),I=1,N)
      WRITE(2,10) K
10    FORMAT(//2X,'VALUE OF COEFFICIENT = ',I4//)
      WRITE(2,6)
      C=DT/(K+0.5*DT)
      Q(1)=0.0
      I=0
      DO 20 I=1,N-1
      Q(I+1)=Q(I)+C*(FIN(I)-Q(I))+0.5*C*(FIN(I+1)-FIN(I))
      WRITE(2,7) I,FIN(I),Q(I)
20    CONTINUE
      WRITE(2,8)
      DO 18 I=1,N
      T(I)=(I-1)*DT
      H1(I)=FIN(I)
18    CONTINUE
1     FORMAT(A)
6     FORMAT(5X,'!',30('-'),'!'/5X,'! S. !',3X,'INFLOW',3X,'!',2X,
     1 'OUTFLOW',3X,'!'/5X,'! NO !',4X,'CUMECS',2X,'!',3X,'CUMECS',
     2 3X,'!'/5X,'!',30('-'),'!')
9     FORMAT(1H0)
7     FORMAT(5X,'!',1X,I2,1X,'!',2(1X,F8.2,3X,'!'))
8     FORMAT(5X,'!',30('-'),'!')
      WRITE(*,*) N
      WRITE(*,500)(T(I),H1(I),Q(I),I=1,N)
500   FORMAT(3F10.3)
      WRITE(*,25)
25    FORMAT(//10X,' DO U WANT TO PLOT HYDROGRAPHS ON SCREEN '/
     1 10X,' ENTER( Y/N) ..... '$)
13    READ(*,1) CHAR
      IF(CHAR.EQ.'Y') GO TO 30
      IF(CHAR.EQ.'N') RETURN
      WRITE(*,12)
12    FORMAT(//10X,' U HAVE ENTERED A WRONG STRING.'/
     1 10X,' WRITE AGAIN .....'$)
      GO TO 13
30    CALL GRAPHX(N,Q)
      RETURN
      END

C***  FUNCTION SUBPROGRAM FOR LINEAR INTERPOLOATION OF VALUES

      FUNCTION POL(VAL,I,J)
      COMMON /ONE/TA(50,4),N
      IF(VAL.LT.TA(1,I)) THEN
      POL=TA(1,J)
      RETURN
      ENDIF
      DO 120 K=1,N
```

```
120    IF(TA(K,I).LE.VAL.AND.TA(K+1,I).GT.VAL) POL=TA(K,J)+(TA(
     1  K+1,J)-TA(K,J))*(VAL-TA(K,I))/(TA(K+1,I)-TA(K,I))
        IF(VAL.GT.TA(N,I)) POL=TA(N,J)
        RETURN
        END

C*      -------- GRAPHICAL REPRESENTATION OF RESULTS -------------
C***   THIS SUBROUTINE IS USED TO PLOT THE INFLOW AND ROUTED
C***   HYDROGRAPHS USING STANDARD  SUBROUTINES AS PROVIDED BY
C***   FORTRAN-77 MICROSOFT COMPILER.  EGA  IS PREREQUISITE FOR
C***   USING THIS SUBROUTINE.

        SUBROUTINE GRAPHX(N,H2)
        CHARACTER*6 TT(50),HH1(50),HH2(50),TITLE*80,A*6,B*6
        COMMON /GRA/T(50),H1(50)
        DIMENSION XCOR(3),YCOR(3),H2(50),X(50),Y(50)
     1  ,IXP(50),IYP(50),HF(20)
        DATA XCOR/100.,100.,630./
        DATA YCOR/30.,280.,280./
        DATA TITLE/'PLOT FOR INFLOW AND ROUTED HYDROGRAPHS'/
1       FORMAT(A)
        DO 106 I=1,N
        WRITE(A,2) T(I)
        READ(A,1) TT(I)
106     CONTINUE
        FX=XCOR(1)
        FY=YCOR(2)
        TMIN=T(1)
        TMAX=T(1)
        HMIN=H1(1)
        HMAX=HMIN
        DO 101 I=2,N
        IF(T(I).LT.TMIN) TMIN=T(I)
        IF(T(I).GT.TMAX) TMAX=T(I)
        IF(H1(I).LT.HMIN) HMIN=H1(I)
        IF(H1(I).GT.HMAX) HMAX=H1(I)
101     CONTINUE
        NU=7
        FAC=(HMAX-HMIN)/NU
        DO 105 I=1,NU+1
        HF(I)=HMIN+(I-1)*FAC
105     CONTINUE
        DO 108 I=2,N
        IF(H2(I).LT.HMIN) HMIN=H2(I)
        IF(H2(I).GT.HMAX) HMAX=H2(I)
108     CONTINUE
        DO 111 I=1,N
        WRITE(B,2) HF(I)
        READ(B,1) HH1(I)
111     CONTINUE
        DX=(TMAX-TMIN)/530
        DY=(HMAX-HMIN)/250
        DO 102 I=1,N
        T(I)=T(I)/DX+100.
        IXP(I)=T(I)
```

```
      H1(I)=230.-(H1(I)-HMIN)/DY
      H2(I)=280.-(H2(I)-HMIN)/DY
102   CONTINUE
2     FORMAT(F6.1)
      CALL GMODE
      CALL GPAGE(1)
      CALL CLRSCR
      CALL LEVEL(1)
      CALL PUTPT(IFIX(XCOR(1)),IFIX(YCOR(1)-10))
      CALL DLINE(IFIX(XCOR(2)),IFIX(YCOR(2)))
      CALL DLINE(IFIX(XCOR(3)+10),IFIX(YCOR(3)))
      CALL PUTPT(IFIX(XCOR(2)),IFIX(YCOR(2)))
      DO 103 I=1,N
      CALL DLINE(IFIX(T(I)),IFIX(H1(I)))
103   CONTINUE
      CALL PUTPT(IFIX(XCOR(2)),IFIX(YCOR(2)))
      DO 104 I=1,N
      CALL DLINE(IFIX(T(I)),IFIX(H2(I)))
104   CONTINUE
      CALL TEXTF(300,330,11,'TIME IN HRS')
      CALL TEXTF(100,10,80,TITLE)
      CALL TEXTF(5,80,1,'D')
      CALL TEXTF(5,100,1,'I')
      CALL TEXTF(5,120,1,'S')
      CALL TEXTF(5,140,1,'C')
      CALL TEXTF(5,160,1,'H')
      CALL TEXTF(5,180,1,'A')
      CALL TEXTF(5,200,1,'R')
      CALL TEXTF(5,220,1,'G')
      CALL TEXTF(5,240,1,'E')
      CALL TEXTF(IFIX(T(N-3)),IFIX(H1(N-3)),17,'INFLOW HYDROGRAPH')
      CALL TEXTF(IFIX(T(N-5)),IFIX(H2(N-5)),18,'OUTFLOW HYDROGRAPH')
      CALL TEXTF((IXP(1)-3),291,1,'¦')
      CALL TEXTF((IXP(1)-40),305,6,TT(1))
      IY=284
      DO 109 I=1,NU+1
      CALL TEXTF(90,IY,1,'-')
      CALL TEXTF(30,IY,6,HH1(I))
      IY=IY-35.5
109   CONTINUE
      DO 107 I=3,N,2
      CALL TEXTF((IXP(I)-3),291,1,'¦')
      CALL TEXTF((IXP(I)-40),305,6,TT(I))
107   CONTINUE
      CALL DISP(1)
      PAUSE
      CALL TMODE
      RETURN
      END
```

Sample Input File for Mass Curve Method

```
   TEST DATA FOR FLOOD ROUTING PROGRAM
  11    26  1.0  6.0
 128               0      0
 130               0      0
 131    7000000     35
 132   16000000     90
 133   25000000    165
 134   33000000    270
 136   51000000    540
 137   70000000    710
 138   85000000    890
 139  100000000   1080
 140  120000000   1310
   0     50    130    250    350    540    735   1215   1800   1400   1050
 900    740    620    510    420    320    270    200    150    100     72
  45     25     10      0
```

Sample Input File for Modified Puls Method

```
TEST DATA FOR FLOOD ROUTING PROGRAM
8,13,1.0,6.0
100.00   3.350    0.0
100.50   3.472   10.0
101.00   3.880   26.0
101.50   4.383   46.0
102.00   4.882   72.0
102.50   5.370  100.0
102.75   5.527  116.0
103.00   5.856  130.0
10.0,20.0,55.0,80.0,73.0,58.0,46.0,36.0,27.5,20.0,15.0,13.0,11.0
100.50
-1
```

Sample Input File for Goodrich Method

```
        TEST DATA FOR FLOOD ROUTING PROGRAM
8,13,1.0,6.0
100.00   3.350    0.0
100.50   3.472   10.0
101.00   3.880   26.0
101.50   4.383   46.0
102.00   4.882   72.0
102.50   5.370  100.0
102.75   5.527  116.0
103.00   5.856  130.0
10.0,20.0,55.0,80.0,73.0,58.0,46.0,36.0,27.5,20.0,15.0,13.0,11.0
100.50
-1
```

Sample Input File for Coefficient Method

```
        RESERVOIR ROUTING BY COEFFICIENT METHOD
2,24,1
0.0,62.5,125.0,187.5,250.0,312.5,375.0,437.5,500.0,468.75,437.5,
406.25,375.0,343.75,312.5,281.25,250.0,218.75,187.5,156.25,125.0,
93.75,62.5,31.25
```

Sample Output File for Mass Curve Method

TEST DATA FOR FLOOD ROUTING PROGRAM

time accumulated (h)	dt (h)	mass inflow m**3/s h	cumulative mass inflow 10**6 m**3	assumed accumulated outflow 10**6 m**3	reservoir volume 10**6 m**3	average spillway discharge m**3/s	outflow for dt 10**6 m**3	cumulative outflow 10**6 m**3
.0	6.0	.00	.00	.00	.00	.00	.00	.00
6.0	6.0	150.00	.54	.09	.45	1.13	.02	.02
12.0	6.0	540.00	2.48	.38	2.10	5.83	.13	.15
18.0	6.0	1140.00	6.59	.91	5.68	17.11	.37	.52
24.0	6.0	1800.00	13.07	1.54	11.53	39.90	.86	1.38
30.0	6.0	2670.00	22.68	3.26	19.42	79.19	1.71	3.09
36.0	6.0	3825.00	36.45	6.65	29.80	153.57	3.32	6.41
42.0	6.0	5850.00	57.51	12.54	44.97	301.53	6.51	12.92
48.0	6.0	9045.00	90.07	23.02	67.05	492.58	10.64	23.56
54.0	6.0	9600.00	124.63	38.00	86.63	701.60	15.15	38.72
60.0	6.0	7350.00	151.09	56.73	94.36	855.09	18.47	57.19
66.0	6.0	5850.00	172.15	76.67	95.48	938.93	20.28	77.47
72.0	6.0	4920.00	189.86	97.54	92.32	960.82	20.75	98.22
78.0	6.0	4080.00	204.55	117.68	86.87	937.24	20.24	118.47
84.0	6.0	3390.00	216.76	136.85	79.91	883.06	19.07	137.54
90.0	6.0	2790.00	226.80	154.11	72.69	812.66	17.55	155.09
96.0	6.0	2220.00	234.79	170.46	64.33	735.97	15.90	170.99
102.0	6.0	1770.00	241.16	184.02	57.14	665.45	14.37	185.36
108.0	6.0	1410.00	246.24	196.56	49.68	592.82	12.80	198.17
114.0	6.0	1050.00	250.02	207.92	42.10	499.64	10.79	208.96
120.0	6.0	750.00	252.72	217.64	35.08	400.39	8.65	217.61
126.0	6.0	516.00	254.58	223.49	31.08	322.62	6.97	224.58
132.0	6.0	351.00	255.84	228.17	27.67	261.35	5.65	230.22
138.0	6.0	210.00	256.60	234.25	22.35	202.12	4.37	234.59
144.0	6.0	105.00	256.98	237.03	19.94	162.49	3.51	238.10
150.0	6.0	30.00	257.08	239.28	17.80	133.74	2.89	240.99

Sample Output File for Modified Puls Method

TEST DATA FOR FLOOD ROUTING PROGRAM

S. NO	ELEVATION METER	STORAGE E+06 M**3	OUTFLOW CUMECS
1	100.000	3.350	.000
2	100.500	3.472	10.000
3	101.000	3.880	26.000
4	101.500	4.383	46.000
5	102.000	4.882	72.000
6	102.500	5.370	100.000
7	102.750	5.527	116.000
8	103.000	5.856	130.000

THE BEGINNING ELEVATION IS 100.500 METER

S. NO	INFLOW CUMECS	OUTFLOW CUMECS	ELEVATION METER	STORAGE E+06 M**3
1	10.00	10.00	100.50	3.47
2	20.00	12.98	100.59	3.55
3	55.00	27.58	101.04	3.92
4	80.00	52.67	101.63	4.51
5	73.00	69.83	101.96	4.84
6	58.00	66.71	101.90	4.78
7	46.00	56.12	101.69	4.58
8	36.00	45.36	101.48	4.37
9	27.50	37.18	101.28	4.16
10	20.00	29.11	101.08	3.96
11	15.00	22.17	100.88	3.78
12	13.00	17.31	100.73	3.66
13	11.00	14.15	100.63	3.58

Sample Output File for Goodrich Method

TEST DATA FOR FLOOD ROUTING PROGRAM

S. NO	ELEVATION METER	STORAGE E+06 M**3	OUTFLOW CUMECS
1	100.000	3.350	.000
2	100.500	3.472	10.000
3	101.000	3.880	26.000
4	101.500	4.383	46.000
5	102.000	4.882	72.000
6	102.500	5.370	100.000
7	102.750	5.527	116.000
8	103.000	5.856	130.000

THE BEGINNING ELEVATION IS 100.500 METER

S. NO	INFLOW CUMECS	OUTFLOW CUMECS	ELEVATION METER	STORAGE E+06 M**3
1	10.00	10.00	100.50	3.47
2	20.00	12.98	100.59	3.55
3	55.00	27.58	101.04	3.92
4	80.00	52.67	101.63	4.51
5	73.00	69.83	101.96	4.84
6	58.00	66.71	101.90	4.78
7	46.00	56.12	101.69	4.58
8	36.00	45.36	101.48	4.37
9	27.50	37.18	101.28	4.16
10	20.00	29.11	101.08	3.96
11	15.00	22.17	100.88	3.78
12	13.00	17.31	100.73	3.66
13	11.00	14.15	100.63	3.58

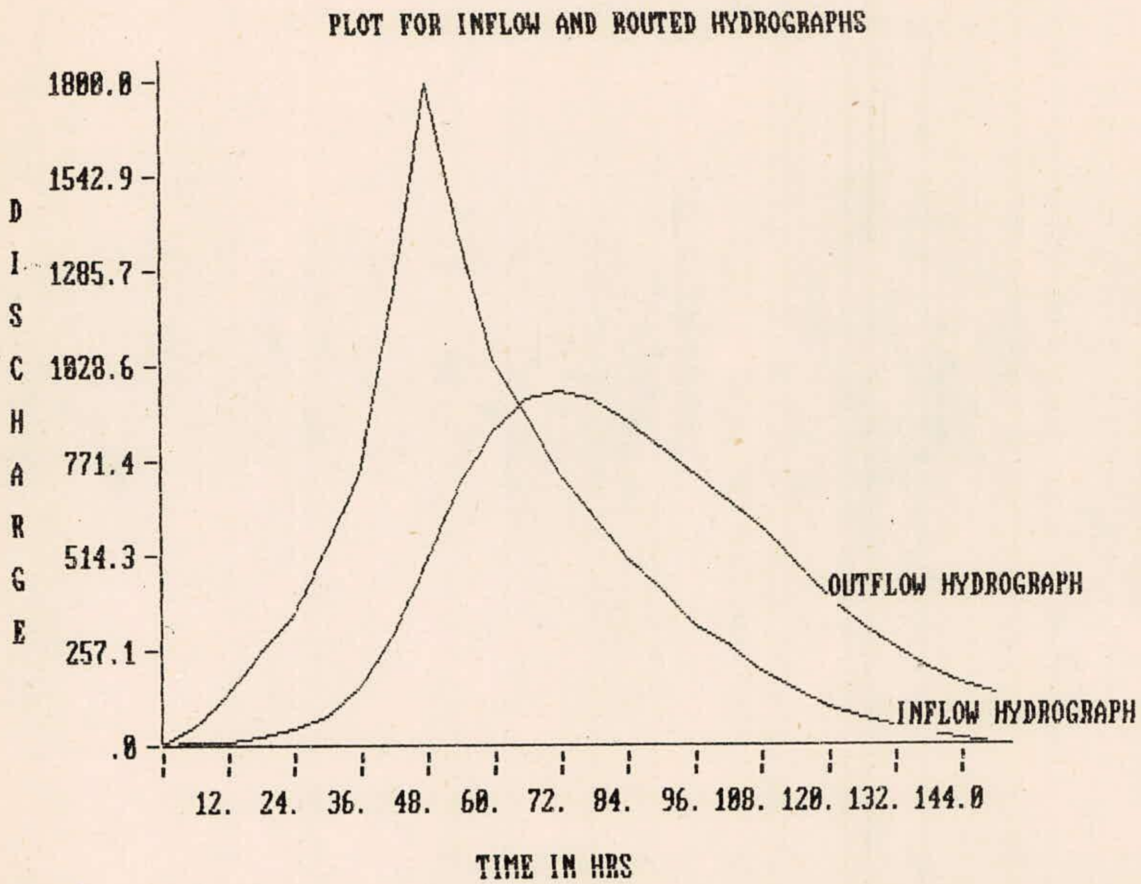
Sample Output File for Coefficient Method

RESERVOIR ROUTING BY COEFFICIENT METHOD

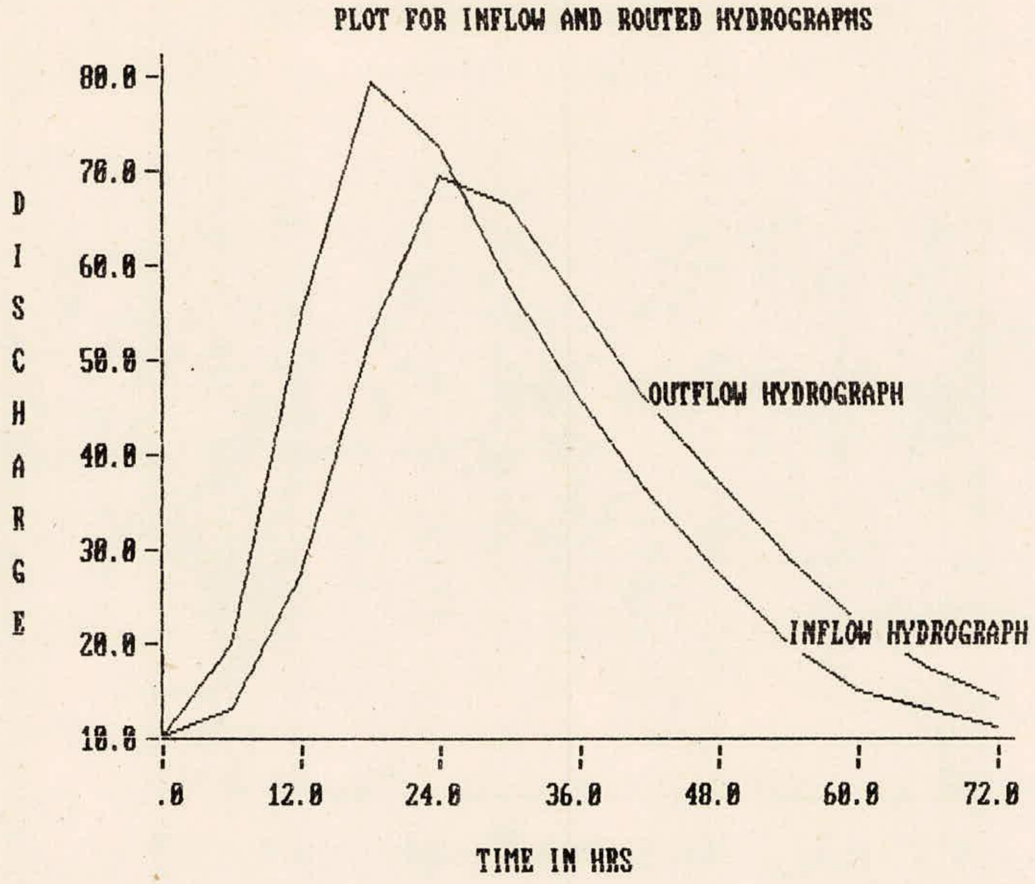
VALUE OF COEFFICIENT = 2

S. NO	INFLOW CUMECS	OUTFLOW CUMECS
1	.00	.00
2	62.50	12.50
3	125.00	45.00
4	187.50	89.50
5	250.00	141.20
6	312.50	197.22
7	375.00	255.83
8	437.50	316.00
9	500.00	377.10
10	468.75	420.01
11	437.50	433.26
12	406.25	428.70
13	375.00	413.47
14	343.75	391.83
15	312.50	366.35
16	281.25	338.56
17	250.00	309.39
18	218.75	279.38
19	187.50	248.88
20	156.25	218.08
21	125.00	187.10
22	93.75	156.01
23	62.50	124.85

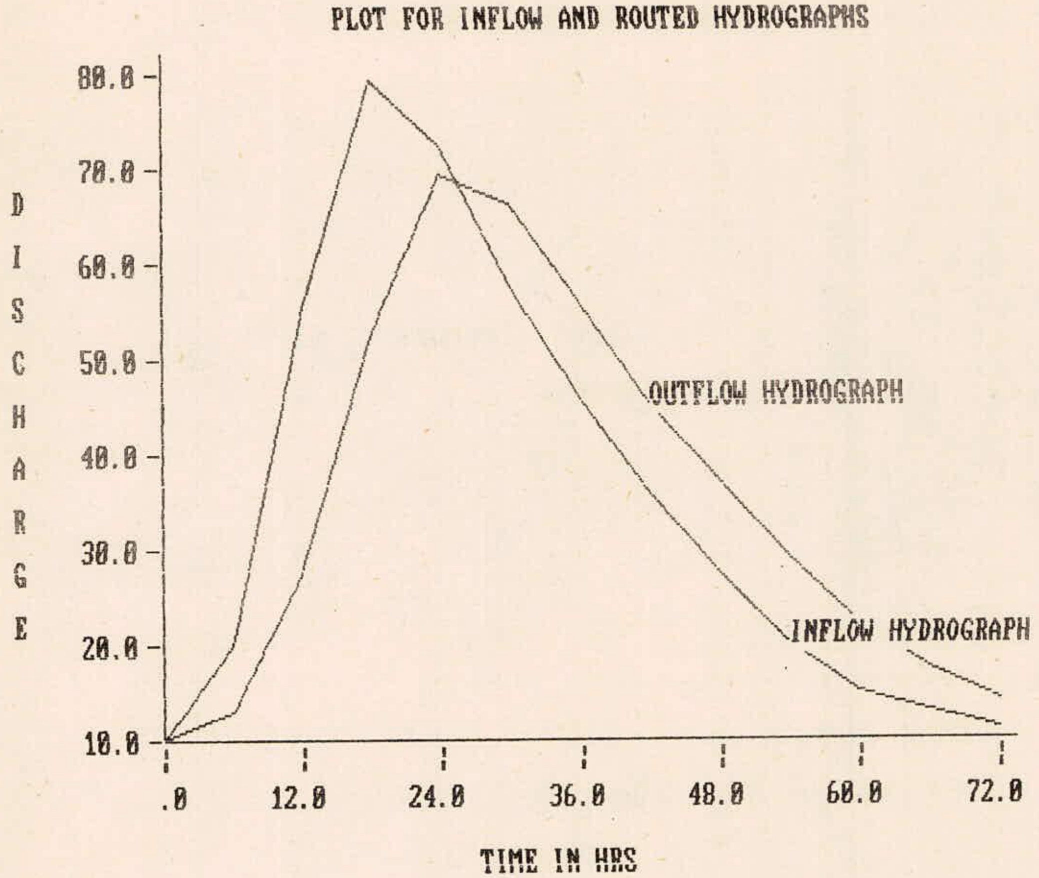
Sample Plot for Mass Curve Method



Sample Plot for Modified Puls Method



Sample Plot for Goodrich Method



Sample Plot for Coefficient Method