DP-5

FLOOD ROUTING (MUSKINGUM CUNGE PROCEDURE)

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1982-83

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ABSTRACT

Flood routing in a natural river is complicated by the presence of irregularities of cross-section and by the presence of lateral flow. It is now possible to quantify the effect of irregularities in the width and the corresponding effect of storage caused by them. These irregular subreaches act as a series of reservoirs and provide attenuation.

Cunge brought out certain salient features of Muskingum method and stated that the attenuation seen in the routed flow using Muskingum model is just becuase of the numerical error and not due to the ability of the model. He showed that the finite difference approximation used in Muskingum method is also an approximation of a diffusion equation using Taylor series expansion. Cunge has developed a method of estimating the attenuation parameter using average width and slope of a river. R.K.Price worked further and improved it to include the variations in the width and slope. The routing parameter x is related to the attenuation parameter.

Based on the value of attenuation parameter and wave speed 'C' using the recurrence relation available in Flood Studies Report, Vol.III of National Environmental Research Council, London, a FORTRAN programme capable of routing the flow was developed in National Institute of Hydrology, Roorkee with following features in addition to routing: (a) finds the attenuation parameter given physical features viz. the widths, slopes, and reach lengths for a given discharge, (b) the lateral flow is obtained as the difference in observed inflow and outflow quantities and distributed as per the ordinates of either inflow or outflow as opted, and (c) the results are plotted in addition to printing of the discrete value.

The programme has been explained fully in the documentation with flow chart. The input specifications and the output descriptions are also given. An example using the data of a flood in the reach between Mortakka and Garudeshwar on the river Narmada is also given in Appendix 1.

1.0 INTRODUCTION

Flood routing is the process of determining the timing and magnitude of a flood wave at successive points along the rivers. This is of great interest to planners and designers. Flood wave movement distinctly includes two phenomena viz.(1) translation (downstream movement without change of form as if moving in a prismatic channel) which takes place in an idealized condition, (2) storage action caused by irregularities of cross-section along the channel. Flood routing is complicated further by the presence of sediment. The presence of flood plain of the river attenuates the flood, when flow enters into it.

It is now possible to quantify and include the effect of irregularities of river geometry. This requires the following data, which are easily available:

1. Topographic map (1:50000) covering the river
2. Flood peak discharges observed and corresponding water levels.
3. Travel time observations.

With these information on the river geometry, the Muskingum-Cunge method can be used to account for attenuation of flood during its passage through the reach. Flood Studies Report Vol.III(NERC, 1975) provides useful information regarding this method. Using this information as a source material a computer programme capable of routing the flood with Muskingum-Cunge approach has been developed, implemented and tested. The table given in section 5.1 compares main features of this programme with the programme given in the above mentioned reference.

2.0 PURPOSE OF THE PROGRAMME

A flood wave as it travels downstream attenuates (reduction in peak) due to the presence of irregularities in the river reach. Cunge's work aims at quantifying the effect of these irregularities. The Muskingum Cunge Method routes the flood through reaches taking the channel geometry into account.

3.0 METHOD USED

All flood routing methods have generally originated from Saint Venant's equations. These equations are used in a much simplified forms of varying approximations. A lumped form of continuity and a simplified form of momentum equation as storage equation are used in flood routing. The storage equation can be arrived at from steady state rating curve. The one to one stage-discharge relationship produces the following continuity equation:

$$\frac{\partial Q}{\partial t} + C \frac{\partial Q}{\partial x} = 0 \qquad \ldots (1)$$

where,

Q is discharge in m^3/sec,

C is celerity of flood wave m/sec, and

x,t are space and time coordinates respectively.

Cunge explained that Muskingum method of routing is finite difference approximation of equation (1) and argued that since this equation inherits a pure translation character rather than attenuation, the flood wave routed using Muskingum method should not produce the attenuation. He further explained that the observed attenuation characteristics of Muskingum method of routing are due to the numerical approximation (truncation error) in the finite difference scheme.

3.1 Calculation of Attenuation Parameters

The areal extent of spread of floods in the flood plain is marked on a map using data of flood records. The river reach is divided into a number of subreaches in such a way that width of flood plain in each of the subreach is approximately uniform. For an inbank flood the subreaches are defined such that the slope of the channel is approximately uniform in each subreach. For each subreach the length L_m of the channel and average slope S_m and plan area P_m (including the plan area of the river channel) are measured from the toposheet. For the whole reach length L of the channel and an average width W_c, the attenuation parameter is calculated as follows:

$$\alpha_p = (1/2) [(1/L) \sum_{m=1}^{M} [P_m/(S_m)^{1/3}]]^{-3} \{ \sum_{m=1}^{M} (P_m)^2/L_m(S_m)^2 \} \qquad \ldots (2)$$

in the case of over bank flood, and

$$\alpha_p = (1/W_c) \{(1/L) \sum_{m=1}^{M} [L_m/(S_m{}^{1/3}]]\}^{-3} \{ \sum_{m=1}^{M} (L_m)/(S_m)^2\} \qquad \ldots (3)$$

in the case of inbank flood.

However, values of α for floods other than those used for marking areal extent of spread of floods in the flood plain are difficult to obtain. A plot of α vs peak flood may be prepared and used for this purpose.

3.2 Calculation of Convection Speed

The convection speed is defined in the following form of continuity equation

$$\frac{\partial Q}{\partial t} + \omega \frac{\partial Q}{\partial x} = 0 \qquad \ldots (4)$$

It is easily possible to find $\bar{C}$ (Q) the average speed along a reach of the flood wave with peak discharge Q, once a steady state rating curve of atleast one gauging station situated in the reach is established. This speed does not allow any possible attenuation. When there is attenuation of the peak discharge, the observed speed of the flood peak is function of $\bar{C}(Q)$ and also of the shape of discharge hydrograph.

Hayami (1951) has derived an expression for incorporating a correction to the average speed as given below:

$$\omega = (L/T_p) - (2\alpha / L^2)Q^*$$

where, Q^* is the attenuation of peak discharge, and

ω is corrected speed

The Figure 1 shows the plot of speed vs discharge as given by R.K.Price in NERC(1975). The shape of the curve is typical of almost all natural rivers. The plot consists of two curves joined by a transition of S shaped curve. From this figure it could be understood that small inbank floods will travel considerably faster than a flood which is just bankful. This is because irregularities in the channel width (at the bankful stage) increase the effect storage of the channel. The storage is magnified when water begins to pond upon the flood plain. As the discharge increases, the speed also increases. For extremely high discharges the whole of the flood plain begins to act like the main channel.

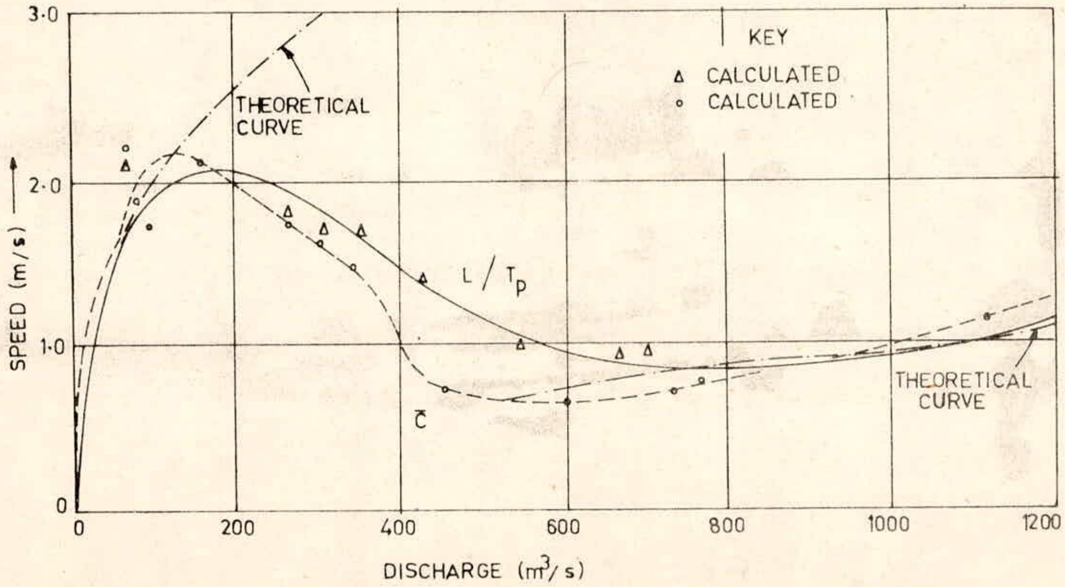

FIGURE 1 - SPEED DISCHARGE CURVE

3.3 Calculation of attenuation of peak discharge (Q^*)

The corrected speed ω, explained earlier and the attenuation of peak discharge are found by an iterative procedure. The travel time T, time to peak t_p of the flood hydrograph are found and the time of occurrence of the peak is located. Two points on the hydrograph at a time interval ∂t on either side of the peak are marked, where ∂t is defined to the nearest hour by $\partial t = t_p/5$. However ∂t need not be greater than 3 hours.

The curvature at the peak is calculated from:

$$\frac{d^2Q_p}{dt^2} = \frac{(Q_1 + Q_{-1} - 2Q_p)}{(\partial t)^2}$$

where, Q_p is the discharge at the peak and Q_1 and Q_{-1} are the two discharges on either side of the peak at ∂t time interval.

$$Q^* = \frac{\alpha_p}{\omega^3} Q_p \left| \frac{d^2 Q_p}{dt^2} \right|$$

where, $\omega = \frac{L}{T}$ initially

If $\frac{Q^*}{Q_p} > 0.1$, Q^* is redefined by

$$Q^*_{new} = Q_p \left[1-\exp\left(-\frac{Q^*}{Q_p}\right)\right]$$

and ω may be redefined using equation (5) if necessary.

3.4 Calculation of Muskingum-Cunge Parameters

The peak discharge Q_p of the flood to be routed is noted and Q^* the attenuation is found out using the procedure explained above. If the down stream peak discharge is known, Q_p is defined as the average of the peaks at each end, otherwise it is defined as given below:

$$Q_p = Q_p - (1/2)Q^*$$

ω and α are defined corresponding to Q_p as per section 3.1 and 3.2 and K and ε are calculated as follows:

$$K = L/\omega$$

$$\varepsilon = (1/2) - (\alpha Q_p / L^2 \omega)$$

The time interval $Dt = \partial t$ is obtained as per section 3.3

The following recurrence formula is used

$$Q_{j+1}^{n+1} = C_1 Q_j^n + C_2 Q_j^{n+1} + C_3 Q_{j+1}^n + C_4$$

where,

Q is the discharge, n refers to time and j refers to space

$C_1 = (K\varepsilon + Dt/2)/(K(1-\varepsilon) + Dt/2)$

$C_2 = (Dt/2 - K\varepsilon)/(K(1-\varepsilon) + Dt/2)$

$C_3 = (K(1-\varepsilon) - Dt/2)/(K(1-\varepsilon) + Dt/2)$

$C_4 = (qDt\ Dx)/(K(1-\varepsilon) + Dt/2)$

where, q is the lateral flow per unit length of the river.

4.0 THE PROGRAMME

```
C   Programme  for routing  a flood  using Muskingum-Cunge method
    REAL Q1(500),Q2(500),X(500)
    DIMENSION TIME(500),QEST(500),QUP(500),QDNP(500),T1(20),T2(20)
    COMMON DX,DT,JX,DXLR,LEND,TH,J1,L1,L2,TITLE(60),JT1,JT2
    COMMON QTRIB1(500),QTRIB2(500),QHYDRO(500),DTHYD,QINIT
    COMMON QINB,QINA,TQIN,TSCQIN,ALPHA,WSP,QCON,QDNS(500)
    COMMON IQH,IQDNS
    OPEN(UNIT=3,FILE='MU1.DAT',STATUS='OLD')
    OPEN(UNIT=32,FILE='MMC.DAT',STATUS='NEW')
    OPEN(UNIT=33,FILE='MUSRT.DAT',STATUS='NEW')
    CALL DATIN
    READ(3,*) PART
    DX=DXLR/FLOAT(JX-1)
    DK=DX/WSP
    IF(ALPHA.EQ.0.0) CALL ALFHA(ALPHA)
    EPSILO=.5*(1.-QCON*ALPHA*2./(DX*WSP*DXLR))
    CC=DK*(1.-EPSILO)+DT*.5
    C1=(DK*EPSILO+DT*.5)/CC
    C2=(DT*.5-DK*EPSILO)/CC
    C3=(DK*(1.-EPSILO)-DT*.5)/CC
    C4=DT*DX/CC
    DLE=DXLR/1000.
    WRITE(32,305) DLE,WSP,ALPHA,QCON,PART,JX,C1,C2,C3
    JXM1=JX-1
    T=0.0
    TOTR=0.0
    QP1=QINIT
    QP2=QINIT
    QDNP2=QINIT
    QDNP1=QINIT
    QDN=QINIT
    QTOT=0.0
    QQQ=0.0
    QQ1=0.0
    DO 145 I=1,LEND
    QQQ=QQQ+QDNS(I)
145 QQ1=QQ1+QHYDRO(I)
    DIFF=QQQ-QQ1
    DO 127 I=1,LEND
127 QHYDRO(I)=QHYDRO(I)*(1+DIFF*PART/QQ1)
    DO 2 J=1,JX
    X(J)=DX*FLOAT(J-1)
    Q1(J) =QINIT
    Q2(J)=QINIT
2   CONTINUE
    DO 14 L=1,LEND
    TIME(L)=L
    T=T+DT
    TH=T/3600.
    QP2=QP1
```

```
      QP1=Q1(JX)
      QDNP2=QDNP1
      QDNP1=QDN
      QDN=QDNS(L)
      Q1(1)=QHYDRO(L)
      DO 4 J=1,JX
      Q2(J)=Q1(J)
4     CONTINUE
      QTOT=0.0
      DO 6 J=2,JX
      Q1(J)=C1*Q2(J-1)+C2*Q1(J-1)+C3*Q2(J)+C4*QTOT
6     CONTINUE
      QEST(L)=Q1(JX)
      QDNP(L)=QDN
      QUP(L)=Q1(1)
14    CONTINUE
305   FORMAT (12X,'The length of the river reach........'F10.2,'KM'/
      112X,        'The speed of the flood wave..........'F10.2,'m/s'/
      212X,        'The attenuation parameter............'F15.2,/
      412X,        'The average discharge................'F8.2/
      512X,        'The lateral flow accounted upstrem...'F8.4/
      612X,        'The number of nodes..................'I8/
      312X,        'The parameters C1,C2,C3..............'3F7.4/)
      READ(3,308)(T1(I),I=1,20)
308   FORMAT(1H,(20A1))
      READ(3,308)(T2(I),I=1,20)
      WRITE(32,186) T1,T2
186   FORMAT(10X,'MUSKINGUM CUNGE METHOD OF FLOOD ROUTING'/
      110X,    '  'PLOT SHOWS OBSERVED HYDROGRPH (O)  AT',1X,20A1,/
      210X,        'AND    ROUTED   HYDROGRAPH (*) AT     ',1X,20A1)
      CALL PLOT (QEST,TIME,LEND,QUP,3,2)
      DO 128 I=1,LEND
128   QEST(I)=QEST(I)+ DIFF*(1-PART)*QDNS(I)/QQQ
      CALL PLOT (QEST,TIME,LEND,QDNP,3,2)
      CLOSE(UNIT=3)
      CLOSE(UNIT=32)
      CLOSE(UNIT=33)
      STOP
      END
      SUBROUTINE DATIN
      COMMON DX,DT,JX,DXLR,LEND,TH,J1,L1,L2,TITLE(60),
      1JT1,JT2,QTRIB1(500),QTRIB2(500),QHYDRO(500),DTHYD,
      2QINIT,QINB,QINA,TQIN,TSCQIN,ALPHA,WSP,QCON,
      3QDNS(200)
      COMMON IQH,IQDNS
      COMMON PART
      READ(3,300)( TITLE(I),I=1,60)
      READ(3,*) JX,LEND,IQH,IQDNS
      READ(3,*)DXLR,DT,DTHYD,QINIT,WSP,ALPHA,QCON
      WRITE(33,355) (TITLE(I),I=1,60)
```

```
355 FORMAT(20X,60A1)
300 FORMAT(1H,(60A1))
    WRITE(33,301) JX,LEND,IQH,IQDNS
301 FORMAT(20X,11I8)
    WRITE(33,*  ) DXLR,DT,DTHYD,QINIT,WSP,ALPHA,QCON,DT
302 FORMAT(20X,F9.2,F7.1,F4.1,F6.2,F8.6,F9.3,2F6.1,F3.2,E9.3,F7.2,F6.2)
    READ(3,*) (QHYDRO(I),I=1,IQH)
    WRITE(22,446) (QHYDRO(I),I=1,IQH)
446 FORMAT(1X,8F10.2)
    READ(3,*) (QDNS(I),I=1,IQDNS)
    WRITE(33,306)
306 FORMAT(1H,18X,4HTIME,10X,8HDISTANCE,6X,10HCALCULATED,6X,
    19HPROTOTYPE/1H ,17X,5H(HRS),13X,3H(M),9X,9HDISCHARGE,6X,
    29HDISCHARGE/)
    RETURN
    END
C
    SUBROUTINE PLOT (CUSEC,TIME,N,QEST,L1,L2)
    DIMENSION TIME(500),CUSEC(500),A(101),QEST(500)
    DATA CHAR,GRID,BLANK,ZERO/1H*,1H+,1H ,1H0/
    QMAX=QEST(1)
    CUMAX=CUSEC(1)
    DO 10 I=1,N
    IF(CUMAX-CUSEC(I))11,9,9
11  CUMAX=CUSEC(I)
9   IF(QMAX-QEST(I))8,10,10
8   QMAX=QEST(I)
10  CONTINUE
    CUMAX=AMAX1(CUMAX,QMAX)
    SF=CUMAX/80.0
    DO 12 I=1,81
12  A(I)=GRID
    WRITE(32,13)(J,J=1,81,10)
13  FORMAT(/2X,'TIME',1X,'LINE',I2,8(6X,I4),4X,' *  ',' 0'/)
    NA=CUSEC(1)/SF+1.5
    NB=QEST(1)/SF+1.5
    I=1
    A(NA)=CHAR
    A(NB)=ZERO
    WRITE(32,14)TIME(I),(A(J),J=1,81),CUSEC(I),QEST(I)
14  FORMAT(1X,F6.1,5X,81A1,F9.3,F9.2)
    DO 15 I=1,81
15  A(I)=BLANK
    K=1
    KC=7
    DO 20 I=L1,N,L2
    KN=TIME(I)-TIME(I-1)
    AA=CUSEC(I)/SF+1.5
    NB=QEST(I)/SF+1.5
    NA=AA
```

```
22   DO 21 I1=1,81,10
21   A(I1)=GRID
     IF(KC-KN-K)24,25,26
24   KP=KC-K
     IF(KP-1)30,30,34
34   DO 31 J=2,KP
31   WRITE(32,91)(A(JJ),JJ=1,81)
91   FORMAT(12X,81A1)
30   DO 32 J=1,81
32   A(J)=GRID
     WRITE(32,92)KC,(A(JJ),JJ=1,81)
92   FORMAT(8X,I4,81A1)
     DO 33 J=1,81
33   A(J)=BLANK
     KN=KN-KC+K
     K=KC
     KC=KC+6
     GO TO 22
25   IF(KN-1) 40,40,41
41   DO 42 J=2,KN
42   WRITE(32,91)(A(J1),J1=1,81)
40   DO 43 J=1,81
43   A(J)=GRID
     A(NA)=CHAR
     A(NB)=ZERO
     WRITE(32,14)TIME(I),(A(J),J=1,81),CUSEC(I),QEST(I)
     K=KC
     KC=KC+6
     GO TO 27
26   IF(KN-1)50,50,51
51   DO 52 J=2,KN
52   WRITE(32,91)(A(JJ),JJ=1,81)
50   A(NA)=CHAR
     A(NB)=ZERO
     K=K+KN
     WRITE(32,14)TIME(I),(A(J),J=1,81),CUSEC(I),QEST(I)
27   DO 28 J=1,81
28   A(J)=BLANK
20   CONTINUE
     KP=KC-K
     IF(KP-1) 60,60,61
 61 DO 62 J=1,81,10
62   A(J)=GRID
     DO 63 J=2,KP
63   WRITE(32,91)(A(JJ),JJ=1,81)
60   DO 64 J=1,81
64   A(J)=GRID
     WRITE(32,91)(A(JJ),JJ=1,81)
     WRITE(32,13)(J,J=1,81,10)
     WRITE(32,95)SF
```

```
95  FORMAT(1X,'THIS GRAPH HAS A SENSITIVITY OF',E10.3,'UNITS/SPAC
    1ING IN THE HORIZONTAL AXIS')
    WRITE(32,96)KC
96  FORMAT(1X,'SENSITIVITY IN THE VERTICAL AXIS IS 1.00 UNITS/LINE
    1'//1X,'TOTAL NUMBER OF LINES IS ',I4,'IN THIS PLOT')
    RETURN
    END
    SUBROUTINE ALFHA(ALPHA)
    DIMENSION DL(200),PM(200),SLO(200)
    READ(3,*) NRE
    READ(3,*) (DL(I),PM(I),I=1,NRE)
    READ(3,*) (SLO(I),I=1,NRE)
    PSM=0.0
    PLS=0.0
    DLE=0.0
    DO 100 I=1,NRE
    PSM=PSM + PM(I)/(SLO(I)**.3333)
    DLE=DLE+DL(I)
100 PLS=PLS+PM(I)*PM(I)/(DL(I)*SLO(I)*SLO(I))
    ALPHA=(0.5*(DLE/PSM)**3)*PLS
    RETURN
    END
```

5.0 INPUT AND OUTPUT DESCRIPTION

The program reads the following data in the same order given in free format except where specified:

1.	TITLE	60A1
2.	JX	Number of space gridpoints
	LEND	Number of time steps
	IQH	Number of data points for the upstream hydrograph
	IQDNS	Number of data points in the downstream hydrograph
3.	DXLR	Length of the reach (in meters)
	DT	Time increment (in Seconds)
	DTHYD	The time increment between data points in the discharge hydrograph (in hours)
	QUNIT	The initial discharge (m^3/sec)
	WSP	Wave Speed (m/sec)
	AP	Attenuation parameter
	QCON	Discharge constant (Qp)(m^3/sec.)
	TDEVN	Time in hour when the calculation of the error parameters are begun (hours)
4.	QHYDRO	Upstream Hydrograph
5.	QDNS	Down stream hydrograph

NOTE: 1. If there is no down-stream hydrograph IQDNS= 0 and TDEVN is set to a value greater than the real time for routing the flood.

Output Description

The programme calculates the parameters and routes the flood. If downstream hydrograph is also given, it calculates the standard deviation of the predicted discharge as a percentage of the average discharge.

The programme prints the discharge along the reach at interval specified by J1. The discharges along the reach are written in L1 time steps and the downstream discharges are written at L2 time steps (not shown).

5.1 A comparison of computer programmes developed in NIH and the one given in NERC(1975) is given below:

TABLE OF COMPARISON

Sl.	NERC 1975 FLOOD STUDIES REPORT Vol.III.	THE PRESENT PROGRAMME
1.	Routes the flow using $Q_{j+1}^{n+1} = C_i Q_j^n + C_2 Q_j^{n+1} + C_3 Q_{j+1}^{n+1} + C_4$	The same recurrance formula is used.
2.	Alpha is an essential input	Optional. If opted computes α from the additional data provided.
3.	Takes lateral flow as a function of time and tributary flow as input hydrograph	Finds the difference between observed inflow and outflow hydrograph distributes the difference according to the respective ordinates optionally either to(1) inflow,(2) routed flow (3) or both.
4.	The routed and observed flows are printed at desired locations of the river reach and at desired time interval.	Prints the results at the interval in which the input is given. Only inflow and the routed and observed flows are printed.
5.	No plots are made	Plots inflow and routed flow. Plots observed and routed flow also.
6.	Routing intervals can be anything. For interval other than of input hydrograph linear interpolation is done.	Routing interval should be the same as input hydrograph.
7.	The input specification are FORMATED	Free FORMAT is used.

6.0 TEST DATA

The programme is tested with a large over bank flood given in NERC (1975) using the data of the river Wye of Great Britain.

The reach is 69.75 km long and has no important tributary and the mean annual lateral inflow along the reach is about 14 m^3/sec. This value is very small when compared to the flood discharge 560 m^3/sec at Belmount. Another important feature of the reach is the large flood plain just 20-30 km upstream of Belmount. This flood plain plays a crucial part in reducing peak discharges at Erwood by regulating the flood at upstream reaches. The curves for L/T_p and C as given in NERC(1975) are shown in Figure 1.

7.0 EXAMPLE CALCULATION

For calculation of attenuation parameters following data has been used:

Width of channel $W_c = 62.0$ m

Length L_m (km)	Flood plain Area P_m (km^2)	Slope S_m (x 10^{-3})
4.5	1.25	2.0
8.3	2.92	2.0
3.0	1.74	0.8
2.9	1.38	0.8
4.5	2.52	0.8
4.6	0.55	0.8
3.5	1.28	0.8
13.6	11.83	0.5
24.9	5.12	0.6
69.8	28.57	0.88

For over bank flood the computation of different terms of equation is as given below:

L_m (km)	P_m (km^2)	P^2_m (km^4)	S_m (x10^{-3})	$(S_m)^2$ (x10^{-6})	$(S_m)^{1/3}$	$P^2_m/(L_m S^2_n)$ (x10^4)	$P_m/S_m^{1/3}$
4.5	1.25	1.563	2.0	4.0	.126	8.683	9.920
8.3	2.92	8.526	2.0	4.0	.126	25.681	23.175
3.0	1.74	3.028	0.8	0.64	.093	157.70	18.709
2.9	1.38	1.904	0.8	0.64	.093	102.58	14.838
4.5	2.52	6.350	0.8	0.64	.093	220.486	27.097
4.6	0.55	0.303	0.8	0.64	.093	10.292	5.914
3.5	1.28	1.628	0.8	0.64	.093	73.125	13.763
13.6	11.83	139.949	0.5	0.25	.079	4116.147	149.747
24.9	5.12	26.214	0.6	0.36	.084	292.436	60.952
69.8						5007.13	324.115

Attenuation parameter α_p is thus given as

$$\alpha_p = \frac{1}{2}\left(\frac{1}{69.8} * 324.115\right)^{-3} *5007.13 \times 10^4$$

$$= \frac{1}{2} * .00998 * 5007.13$$

$$= 25.005 \times 10^4$$

$$= .25 \times 10^6$$

For inbank flood the computations are as below as per equation (3)

L_m (km)	S_m ($\times 10^{-3}$)	S_m^2 ($\times 10^{-6}$)	$S_m^{1/3}$	$(L_m/S_m^{1/3})$	$(L_m/S_m^2$ ($\times 10^6$)
4.5	2.0	4.0	.126	35.714	1.125
8.3	2.0	4.0	.126	65.87	2.075
3.0	0.8	0.64	.093	32.26	4.688
2.9	0.8	0.64	.093	31.18	4.531
4.5	0.8	0.64	.093	48.38	7.031
4.6	0.8	0.64	.093	49.46	7.187
3.5	0.8	0.64	.093	37.63	5.469
13.6	0.5	0.25	.079	172.15	54.40
24.9	0.6	0.36	.084	296.43	69.16
				769.074	155.666

Attenuation parameter α_p is thus given as :

$$\alpha_p = \frac{1000}{} \times .0007459 \quad *155.666 \times 10^6$$

$$= .9385 \times 10^6$$

8.0 RECOMMENDATIONS

It has been well established that Muskingum-Cunge method of flood routing predicts attenuation accurately. This method has been used in Britain and found successful (NERC 1975). When the available data permits its use, this method appears to be better to include attenuation character of a flood effectively. The necessary data include high flood marks on the plan form of a river and the irregularities of the river as defined by cross sections. It may also be noted that the variation of the attenuation parameter α with discharge is to be evaluated from the past flood records.

The programme and the input are given in Appendix 1. The observed hydrograph and routed hydrograph for the site Garudeshwar are output as a plot. The observed hydrograph at Mortakka of the river Narmada and routed hydrograph at Garudeshwar are also output as plots. These plots are also shown in Appendix 1.

It could be seen that the routed hydrograph at Garudeshwar nearly matches the observed one.

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APPENDIX 1

APPLICATION TO DATA OF FLOOD IN NARMADA RIVER

The method is used in routing 1978 flood observed at site Mortakka to Garudeshwar of the river Narmada. The topographic maps were used to deduce the data required (viz.,slope, width and length of the reaches of uniform length). The attenuation parameter is computed as described in section 3.1.

The total length of the river reach considered is about 25o km. This length of river reach is too long for routing purposes. Experience showed that the routing parameter x will be aproaching 0.5 and is insensitive to the length. Hence the total length is divided into sub reaches. In the present case the reach is divided into 5 sub reaches to keep the sub reach length within a range of 30 km to 60 km. This range of length is found good by trials for routing.

INPUT

```
FLOODROUTING BETWEEN MORTAKKA AND GARUDESHWAR - NARMADA
        5        96        96        96
295500.00  10800.00  10800.00   2818.00      5.50 911800.00  30000.00   3600.00
  2798.86   2798.87   2798.86   2911.53   2944.01   3042.20   3158.20   3191.60
  3258.82   3515.17   4324.19   5736.22   6601.11   7757.98   9099.64  10514.83
 11893.91  13248.74  14086.02  14397.52  15521.04  18070.54  19728.07  20046.54
 20046.54  19791.63  20110.44  19791.63  19696.34  19033.88  17306.58  15346.26
 13525.84  12268.07  11445.08  11340.33  10744.73  10035.14   9711.48   9835.52
 10185.76  10185.76 164405.30  20947.65  22292.08  24414.49  26322.11  28822.11
 30101.69  29368.10  26851.12  23395.36  20110.45  18070.54  16853.82  15667.22
 14941.18  14086.02  13387.04  12429.67  11497.58  10591.29   9835.52   9220.90
  8620.35   8266.90   7803.79   7689.47   7462.63   7171.36   6579.52   6471.89
  6047.70   5839.41   5715.68   5511.52   5330.04   5210.25   5071.71   4953.98
  4779.25 460674.00   4455.27   4361.50   4194.52   4102.73   3957.37   3885.40
  3225.15   3637.14   3549.87   3377.59   3411.81  32258.82   3174.88   3108.31
  3355.75   3274.57   3171.36   3108.93   2991.13   2913.60   2880.62   2809.69
  2766.38   2739.45   2755.60   2820.56   2891.60   3194.18  34002.50   3964.55
  4287.13   4819.83   6994.41   9691.14  11541.24  12745.84  13946.13  15562.50
 16792.96  17890.01  18609.75  18956.43  18956.43  18956.43  18949.02  18949.02
 18667.36  18037.58  17103.57  16080.62  14808.54  13772.04  13034.38  12283.66
 12079.09  11990.13  11723.50  11408.50  11408.50  12069.30  16859.47  25622.52
 29042.19  31174.96  33760.42  36246.83  37394.61  37882.13  37166.96  35187.45
 32127.74  28946.03  25648.67  23287.07  21551.45  20225.51  19014.47  18460.30
 17878.68  17450.12  17686.43  17709.01  17181.60  16781.90 155745.23  14956.03
 13874.33  12785.48  12157.04  11465.16  10900.99  10357.31   9842.62   9443.59
  8930.62   8631.68   8387.06   8103.83   7678.17   7388.86   6815.86   6570.51
  6336.24   6127.56   5965.56   5805.29   5618.12   5475.80   5327.94   5126.41
  0.0
```

ROUTED	OBSERVED
3612.51	2739.45
12362.71	9691.14
23762.16	18956.43
13958.60	12283.66
30377.32	31174.96
21086.55	23287.07
11882.75	16781.90
7515.44	7443.85
5375.78	6127.56

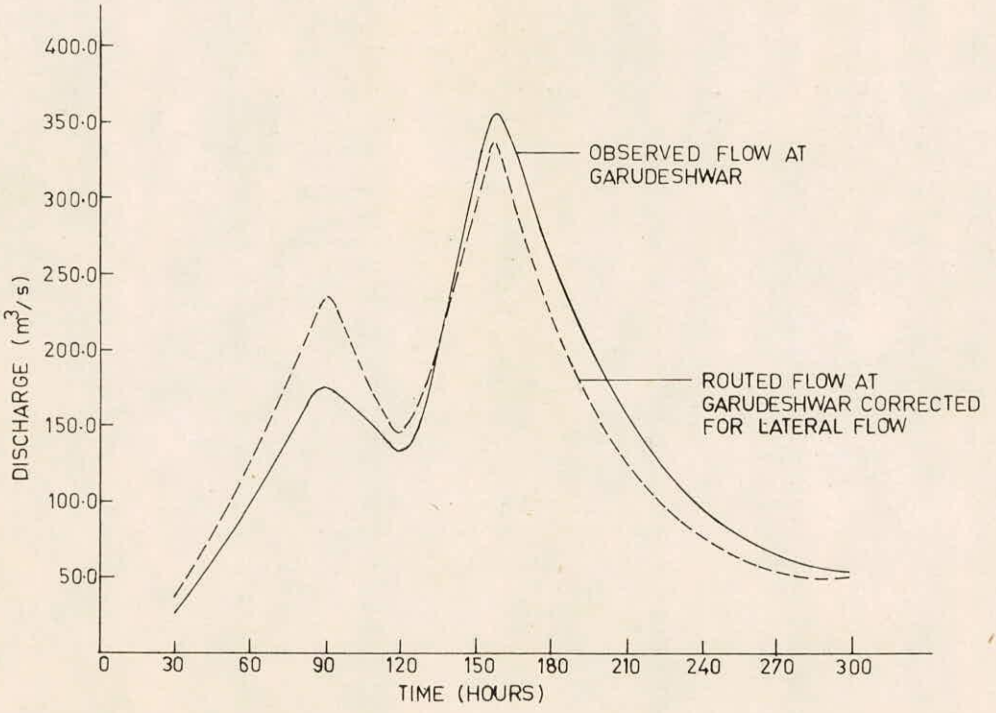

FIGURE 2 - OBSERVED AND CALCULATED HYDROGRAPH AT GARUDESHWAR

ROUTED FLOW AT GARUDESHWAR	FLOW AT MORTAKKA
3043.96	3515.17
10351.40	14397.52
19836.03	17306.58
11401.24	9835.52
23907.23	29368.80
16253.58	12429.67
8399.81	7171.36
5555.44	4953.98
4104.06	3607.14

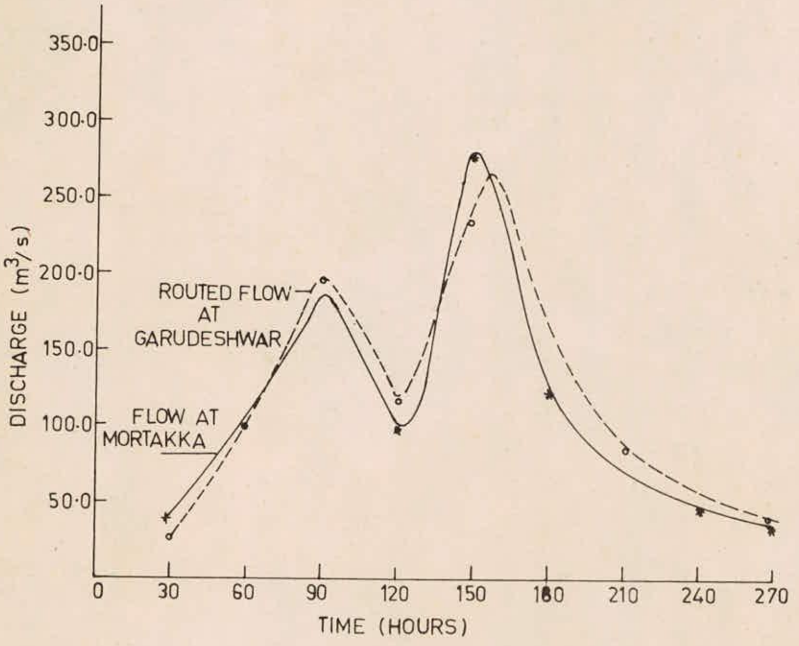

FIGURE 3 - UPSTREAM AND ROUTED DOWNSTREAM HYDROGRAPHS