CS-13

APPLICATION OF MUSKINGUM-CUNGE METHOD OF FLOOD ROUTING

SATISH CHANDRA
DIRECTOR

STUDY GROUP

A B PALANIAPPAN

S M SETH

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE-247667(U.P.)
INDIA

1985-86

CONTENTS

Page No.

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In all water resources development activities floods play an important role, hence measures have to be taken to control floods and also to design hydraulic structures capable of withstanding the adverse effects. The time and magnitude of a flood wave at a point on-stream is determined from the known or assumed data at one or more points up-stream, using the procedure of flood routing. There have been a variety of flood routing procedures which have been developed involving various assumptions about the flow and channel characteristics depending upon available data. The Muskingum Cunge procedure is one such procedure which considers the attenuation effect on the flow during its passage through a river reach due to irregularities in the cross-section and storage effect, This procedure, which is a modification of commonly used Muskingum procedure, includes consideration of the effect of channel geometry. In the present case study, this procedure has been applied to data of two floods observed in a reach of river Narmada.

The information regarding river geometry and flood plain geometry has been derived from toposheets (1:50,000) scale for river reach between Mortakka and Garudeshwar sites. At all points where river channel pattern is changing,cross-section information has been derived from the contours. Using this information, the attenuation parameter for both in-bank and over-bank floods have been established for the river reach, and using the data for inflow hydrograph at Mortakka site and

the parameters derived as above, the downstream hydrograph at Garudeshwar site has been computed and compared with the observed hydrograph. These computed hydrographs compare reasonably well inspite of limitations due to river geometry information taken from contours at 20 m intervals.

1.0 INTRODUCTION

The method of determining the flood hydrograph at a section, using the data on the same at an upstream site is known as flood routing. These methods are needed for many hydrologic applications like flood forecasting, flood protection, reservoir design, spillway design etc. Different methods have been developed and practiced for routing a flood. They can be broadly classified into two types viz. (i) hydraulic routing, (ii) hydrologic routing. The former considers the flow to be gradually varied unsteady and solves partial differential equations. The latter aims at computationally simplified approach by using routing parameters. These parameters are chosen so that they are able to reproduce the outflow hydrograph. Two distinct effects, on the hydrograph, of these parameters are noted. They are (i) the translation of flood wave without change of form (ii) the attenuation, which is a reduction in flood peak.

The Muskingum method uses a trial and error method to arrive at the two parameters. Later methods were found to evolve physically meaningful determination of these parameters. The Muskingum Cunge is one such method. With the information on the river geometry, this method finds an attenuation parameter, which can be used to determine the routing parameter x. Because of the use of information on the river geometry this method provides a scope of extending its application to floods larger than earlier observations.

In order to illustrate its use, applications of this method to route some floods experienced in the river Narmada has been made. The information on river geometry has been extracted from the topographic maps (1:50000 scale) covering the river reach between the Mortakka and Garudeshwar sites on the river Narmada.

2.0 REVIEW

A flood may emanate from precipitation runoff, reservoir releases or a dam break. Theoretical foundation for flood routing was laid by Saint-Venant in 1871, with the development of one dimensional equation of unsteady flow. The St. Venant equations express the conservation of mass and momentum as follows:

Continuity:

$$\partial Q/\partial x + \partial A/\partial t = 0 \qquad \ldots (1)$$

Momentum:

$$\frac{\partial A}{\partial t} + \left(\frac{Q}{A}\right) \frac{\partial Q}{\partial x} + Ag \left(\frac{\partial y}{\partial x} - S_o + S_f\right) = 0 \qquad \ldots (2)$$

where,

Q is the discharge (m^3/s),

A is the area of cross section of flow (m^2),

y is the depth of flow (m),

g is the acceleration due to gravity (m/s^2),

S_o is the bed slope,

S_f is the energy slope,

x,t are space and time coordinates.

These equations are too complex to solve and hence various simplified forms are derived to solve flood propagation. A bibliography of the works carried out on flood routing can be seen in Miller, et al (1975). The solution procedures for the flood propagation can be classified under two categories viz., (i) hydrologic flood routing, (ii) hydraulic flood routing.

Hydrologic routing methods use simplified forms of equations 1 and 2. The continuity equation takes the following form:

$$I - O = ds/dt \qquad \dots (3)$$

Instead of the usual momentum equation given earlier, hydrologic flood routing methods adopt storage equation as follows:

$$S = K(x I - (1 - x) O) \qquad \dots (4)$$

where,

I is an average inflow over time dt

O is an average outflow over time dt

S is storage

K, x are routing parameters determined from flood records

In case of hydraulic flood routing the St. Venant equations are solved with appropriate boundary conditions by any of the following methods:

1. Finite difference method
2. Method of characteristics
3. Finite element methods

A review of hydraulic routing methods can be seen in Hydraulic Routing Techniques, NIH RN-21 (1985-86).

2.1 Hydrologic Methods

Muskingum method was developed by McCarthy and was named after the place of its first application. This is based on equation 4. The parameters 'K' and 'x' are evaluated from the flood hydrolographs observed at the upstream and downstream sites. Originally a trial and error method was used in this connection. The methods of determination of these parameters have been developed by many investigators (Singh and McCann, 1980) such as (1) least square techniques, (2) Method of moments, (3) Optimization techniques. Singh and McCann concluded that there is no particular advantage of one method over the other.

The Muskingum method suffers due to two short comings. Firstly, the establishment of the routing parameters are tedious. Secondly, they can only be evaluated for reach having both ends gauged. In many situations, the gauging sites might not have been in operation during high floods. Hence, there is a need for a method which uses the available topographic information and other geometric information to compute the routing parameter.

Commenting on the Muskingum method, Cunge (1969) mentioned that the finite difference approximation (truncating higher order terms) to the modified continuity equation, produces attenuation in this method. Relating the truncation error to the Hyami's(1951) diffusion equation, Cunge derived expressions for attenuation parameters and routing parameters using average channel width and slope. The most convenient way of determining the attenuation and routing parameters, was proposed by Price (1973) as given in NERC (1975). In this method, the irregularities in the width of the river are appropriately included.

3.0 METHOD USED

3.1 Theoretical Basis of the Method Used

The relative importance of various terms in the basic equation 1 and 2 has been given by Henderson (1966, P. 364). The local and convective acceleration terms can be ignored. Thus the equation 2 is reduced to:

$$S_f + \frac{\partial y}{\partial x} - S_o = 0 \qquad \ldots (5)$$

The energy slope S_f can be evaluated by the Manning's:

$$S_f = \frac{Q^2 n^2}{A^2 R^{4/3}} \qquad \ldots (6)$$

Substituting the expression for Q from (5), (6) into (1) the following are derived:

$$\frac{\partial A}{\partial t} + \frac{\partial}{\partial x} \left(\frac{1}{n} AR^{2/3} (S_o - \frac{\partial y}{\partial x})^{1/2} \right) = 0 \qquad \ldots (7)$$

where,

n is the Manning's coefficient,

R is the hydraulic radius

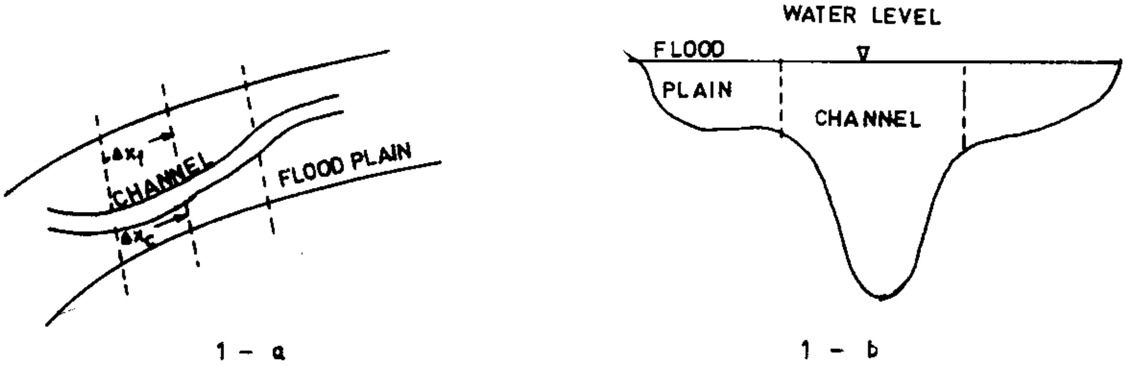
The flood flow can be sub-divided into a discharge Q_c flowing in the channel and a discharge Q_f flowing over the flood-plain. This division is only arbitrary. Now the continuity equation (1) can be rewritten as:

$$\frac{\partial}{\partial t}(A_c + \sigma A_f) + \frac{\partial Q}{\partial x} = 0 \qquad \ldots (8)$$

Assuming A_f to be a function of A_c the above can be reduced to:

$$(1 + \sigma \frac{\partial A_f}{\partial A_c}) \frac{\partial A_c}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad \ldots (9)$$

Here, W_c and W_f are the inundated widths of the channel and flood plain respectively. The above assumption is true only if the water level across the channel and flood plain is uniform. The term σ is sinosity and is defined as the ratio of the length of the channel to the length of the flood plain in the flow direction. These are explained in figure 1.



1 – a

1 – b

FIG.1 Channel and flood plain

From the equations (5) and (6) the discharge can be expressed as:

$$Q = Q_c + Q_f = (A_c R_c^{2/3}/n_c + \sigma^{3/2} A_f R_f^{2/3}/n_f)(S_o - \frac{\partial y_c}{\partial x})^{1/2} \qquad \ldots (11)$$

Differentiating Q with respect to time t,

$$\frac{\partial Q}{\partial t} = \frac{R_c^{2/3}}{n_c}(1+\frac{2}{3}\frac{A_c}{R_c}\frac{\partial R_c}{\partial A_c}) + \frac{\sigma^{2/3}}{n_f}\frac{\partial}{\partial A_c}(A_f R_f^{2/3}) (S_o-\partial y_c/\partial x)^{.5}\partial A_c/\partial t - .5Q(S_o-\partial y_c/\partial x)^{-5} \partial(\partial A_c/\omega_c\partial t) \qquad \ldots (12)$$

Substituting $\partial A_c/\partial t$ from equation (9) and replacing the hydraulic depth R by the depth y, assuming the width to depth ratio is large, the following can be deduced:

$$\frac{\partial Q}{\partial t} + C\left(1 - \frac{1}{S_o}\frac{\partial Y_c}{\partial x}\right)^{3/10} \frac{\partial Q}{\partial x} =$$

$$- \frac{1}{2} Q \left(S_o - \frac{\partial Y_c}{\partial x}\right)^{-1/2} \frac{\partial}{\partial x}\left(\frac{1}{\lambda W_c} \frac{\partial Q}{\partial x}\right) \qquad \ldots (13)$$

where,

$$C = \frac{Q}{\lambda (Q_c\ n_c)^{3/5}\ W_c^{2/5}\ S_o^{3/10}} \left\{ 1 + \frac{2}{3}\frac{A_c}{R_c}\frac{\partial R_c}{\partial A_c} + \theta \right\} \ldots \quad (13a)$$

$$\lambda = 1 + \sigma\ W_f/W_c$$

and,

$$\theta = \sigma^{3/2}\ \frac{A_f\ R_f^{2/3}}{n_f} \left\{ \frac{A_c}{A_f}\ \frac{W_f}{W_c}\left(1 + \frac{2}{3}\frac{A_f}{R_f}\ \frac{\partial R_f}{\partial A_f}\right) - \left(1 + \frac{2}{3}\ \frac{A_c}{R_c}\ \frac{\partial R_c}{\partial A_c}\right)\right\}$$

$$\left(\frac{A_c\ R_c^{2/3}}{n_c} + \sigma^{3/2}\ \frac{A_f\ R_f^{2/3}}{n_f}\right)^{-1}$$

If flood plain is not inundated $\theta = 0$; and $\lambda = 1$. Finally assuming $\partial Y_c/\partial x$ is small when compared to bed slope S_o, the equation (13) is reduced to:

$$\frac{\partial Q}{\partial t} + C\frac{\partial Q}{\partial x} = Q\frac{\partial}{\partial x}\left(\alpha \frac{\partial Q}{\partial x}\right) + \alpha \frac{Q}{S_o}\frac{ds_o}{x}\ \frac{\partial Q}{\partial x}$$

$$+ \frac{3}{5}\ \phi\left(\frac{\partial Q}{\partial x}\right)^2 \qquad \ldots (14)$$

where,

$$\alpha = 1/2\ \lambda W_c\ S \qquad \phi = 1/2\ W_c\ S_o \qquad \ldots (15)$$

The solution of equation (14) with right hand side being zero is a Kinematic wave solution. The terms on the right hand side modify the kinematic wave solution.

NERC (1975) confined the attention to the following from deduced from equation:

$$\frac{\partial Q}{\partial t} + C\frac{\partial Q}{\partial x} = \frac{\alpha}{L} Q \frac{\partial^2 Q}{\partial x^2} \qquad \ldots (16)$$

3.2 Attenuation Parameters (α)

The flood routing method based on equation (15) requires the definition of α as a function of Q. The method of evaluation of this is to divide the river reach into several sub-reaches in such a way that the width of the flood plain in each sub-reach is approximately uniform. NERC(1975) gives the following relationship:

$$\alpha(Q) = \frac{1}{2}\left\{\frac{1}{L}\sum_{i=1}^{M}\frac{P_i}{S_i^{1/3}}\right\}^{-3}\sum_{i=1}^{M}\left(\frac{P_i^2}{L_i S_i^2}\right) \qquad \ldots (17)$$

where, P_i is the plan area of the inundated floodplain and channel in the i^{th} sub-reach.

L_i and S_i are corresponding length and slope of these sub-reaches respectively.

In case of small floods where in flood plains are not inundated, the following can be used.

$$\alpha = \frac{1}{2W_c}\left\{\frac{1}{L}\sum_{i=1}^{M}\frac{L_m}{S_m^{1/3}}\right\}^{-3}\sum_{i=1}^{M}\left(\frac{L_m}{S_m^2}\right) \qquad \ldots (18)$$

However, NERC (1975) states that the intermediate values of $\alpha(Q)$ for different floods are much more difficult to obtain unless there are data available on the extent of flooding by different overbank flooding.

The following steps are to be used for this purpose:

i) Divide the river reach into subreaches where the sub-reach has uniform width defined by contours. If the extent of inundation is known, this can be done by marking the flood plain.

ii) For each sub-reach, measure L_i, the length of the channel, the average slope S_i of the channel and the plan width.

iii) Compute plan area P_i for each sub-reaches

iv) Use the equation (17) to computer α^{-}

3.3 Convection Speed

This speed is defined as the average speed along a reach of the flood wave having the peak discharge Q under the condition that there is no attenuation. This condition is equivalent to steady state rating curve. The observed speed will normally involve the attenuation of flood peak. This observed speed depends upon the shape of the hydrograph. Hayami (1951) suggested a correction to (L/T_p) the observed speed:

$$\omega = \frac{L}{T_p} - \frac{2\alpha}{L^2} Q^* \qquad \ldots (19)$$

The estimation of (L/T_p) is difficult when there are strong lateral inflows and large tributary inflows. It is advisable to plot (L/T_p) against the value of Q_p for the combined flow. The equation (13a) can be used when roughness coefficients can be evaluated. But this would be difficult.

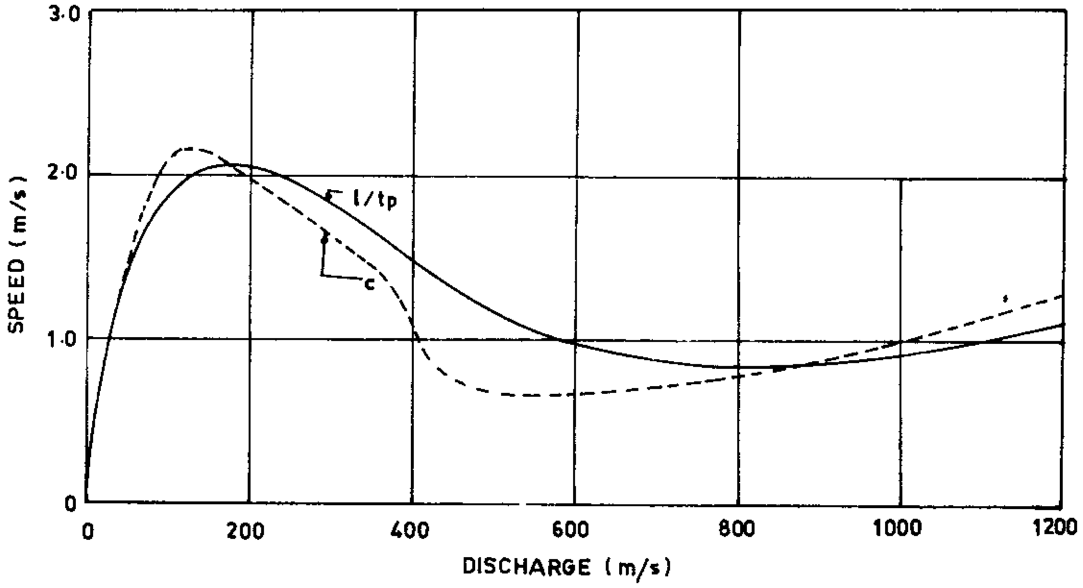


FIG.2 Variation of speed with discharge

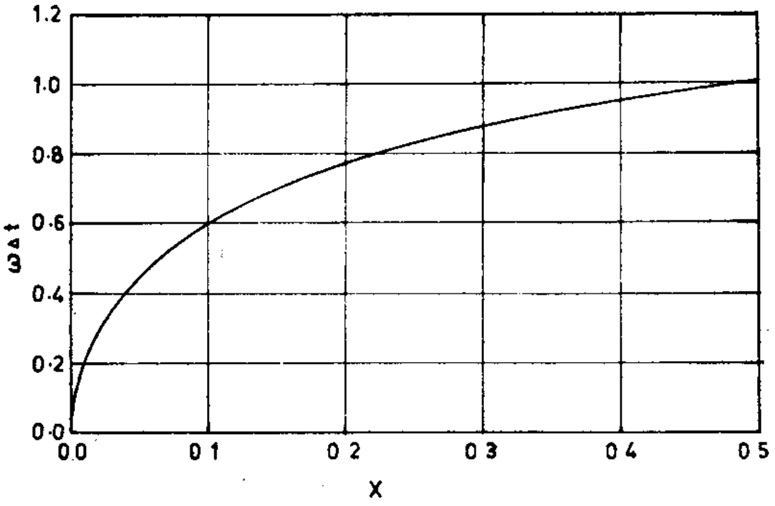


FIG.3 Cunge's curve for Δt

Price (1973) found that C (speed of the wave) is strongly dependent upon d $(L/T_p)/dQ$ and on Q*, the attenuation gave the following expression.

$$C = \omega + Q^* \frac{d(L/T_p)}{dQ} \qquad \ldots (20)$$

where, ω is given by equation (18).

The figure 2, shows the variation of and (L/T_p) with respect to discharge Q. It can be noted that the curves for (L/T_p) and C intersects where $d(L/T_p)/dQ \approx 0$.

The value of C is maximum for a discharge which is usually less than the average bankfull discharge along the reach. This shows that small in-bank floods will travel considerably faster than a flood which is just bankfull. The main reason for this effect is that the river channel generally has a more irregular surface width as the depth of water increases. The irregularities increase the effective storage of the channel. This storage is magnified when water begins to pond upon the flood plain. For some discharge greater than bankfull discharge the speed C will be minimum, and thereafter C will increase with an increase in discharge. Steps for calculation of convection speed are as follows:

i) Extract the travel time T_p for as many recorded floods as possible

ii) Calculate the curvature of the peak from:

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

Q_1, Q_{-1} are two points on the hydrograph at time interval

∂t, on either side of the peak. (∂t may be taken to be $T_p/5$).

iii) Calculate attenuation of the peak

$$Q^* = \frac{\alpha}{(L/T_p)^3} \; Q_p \left| \frac{d^2 Q_p}{dt^2} \right|$$

If Q^* is greater than 10% of Q_p re-define Q^* by

$$Q^* = Q_p \; (1 - e^{(-Q^*/Q_p)})$$

iv) Define

$$\omega = \frac{L}{T_p} - \frac{2\alpha}{L^2} \; Q^*$$

3.4 Routing Parameters and the Recurrence Relations

The following equations are used to arrive at the parameters:

$$K = L/\omega$$

$$x = \frac{1}{2} - \alpha \; Q_p/L^2 \omega$$

Refering to figure 3 taken from Cunge (1969), $(L/\omega\Delta t)$ can be read for the computed x value and then compute Δt value. The value of Δt can be adjusted to a whole number in such a way that the value $(L/\omega\Delta t)$ less than the value read of.

Routing is achieved using the following recurrence formula.

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

where,

$$C_1 = (Kx + 0.5 \; \Delta t)/(K \; (1-x) + 0.5\Delta t)$$

$$C_2 = (0.5\Delta t - kx)/(K \; (1-x) + 0.5\Delta t)$$

$$C_3 = (K \; (1-x) - 0.5\Delta t)/ (K(1-x) \quad 0.5\Delta t)$$

j refers to the jth site

n refers to the nth time

A computer programme developed here for the above purposes is given in appendix 1.

4.0 DESCRIPTION OF THE STUDY AREA

In order to illustrate the application of Muskingum Cunge method of flood routing data of river, the Narmada was choosen mainly because of the data of this river was readily available with National Institute of Hydrology. The toposheets available cover the reach between Mortakka to Garudeshwar and hence this reach has been used in this study.

4.1 The River

The river Narmada, situated in the Central India is a west flowing river, rising near Amarkantak in Madhya Pradesh at an elevation of about 900 m in Maikala range. The river Narmada has several falls in the head reaches. The river drops by 24 m at Kapildhara fall at 8 km from the source and 4.6 m drop at Dudhara falls very near to the former. Close to Jabalpur the river drops 15 m at Dhaundhara falls after flowing through 404 km from the source. After travelling 464 km the river Narmada enters the upper fertile plains. The river drops again 12 m both at Nandhar, 806 km from source and at Dhardi 853 m from the source, while its journey in the middle plains. A drop of 6.7 m at Sahasradhara can be seen at 966 km from the source. After the middle plain the river enters the lower hilly regions and flows through gorge. Emerging from the gorge the river enters the lower plains and meanders till it reaches Broach. Beyond Broach the valley widens into an estuary and enters the Gulf of Gambay.

In its 1312 km journey the river Narmada receives flows from number of tributaries. Some of the major

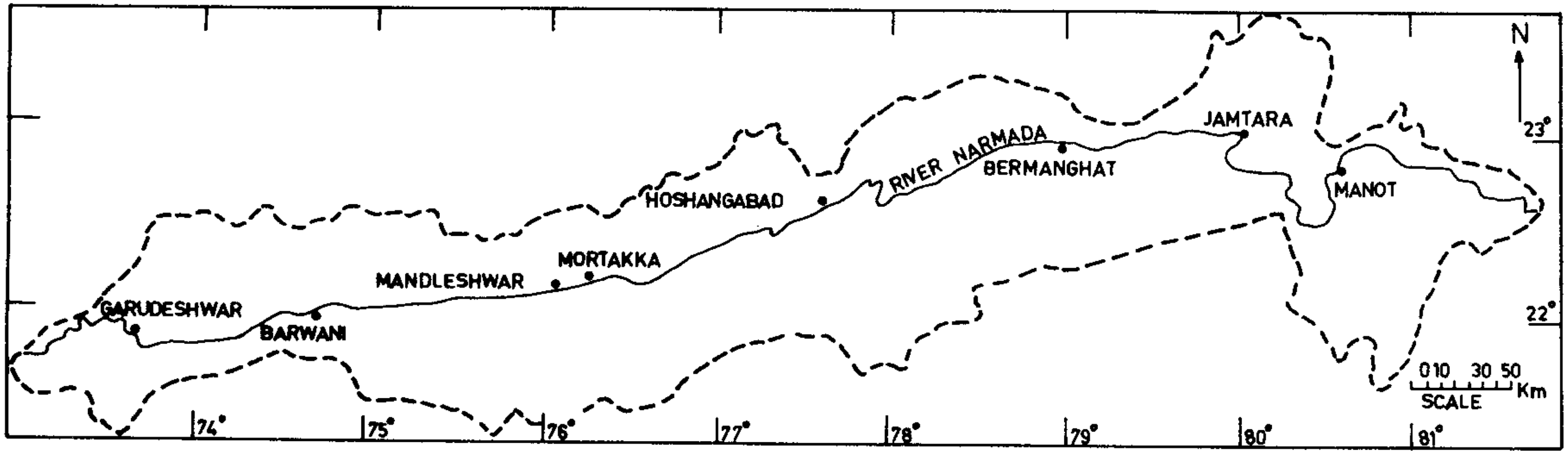


FIG.4 Index map showing gauging sites on the river Narmada

tributaries are Burhner, Banjer, Sher, Shakkar, Tawa, Chhota Tawa and Kundi.

The Narmada basin is bounded by Vindhyas on the north, Maikala range on the east, the Arabian sea on the west and the Sathpuras on the south. The hilly regions are well forested. The upper, middle and lower plains are broad and fertile areas well suited for cultivation.

So far as the main river is concerned there are seven important discharge sites as marked in figure 4. Observations are reported to be carried out daily using current meters. In case of high floods, floats are used to measure velocity of the flow.

5.0 AVAILABILITY OF DATA

The hydrological observations in Narmada basin were started in the year 1942. The then Central Water Ways, Irrigation and Navigation Commission (CWINC) commenced its gauge observation on 1948. The Table 1 lists the gauging stations at present operating on the main Narmada basin.

Table 1 : Gauge and discharge sites on the main river Narmada

No	Name	zero of gauge (m)	Width (m)	Slope	Lat	Lon
1.	Manot	442.0	170	.00125	22°44'	80°30'
2.	Jamtara	360.0	280	.00033	23°04'	79°57'
3.	Bermanghat	306.0	320	.00038	23°02'	79°07'
4.	Hoshangabad	282.0	700	.00023	22°48'	77°45'
5.	Mortakka	150.0	670	.00053	22°10'	75°58'
6.	Mandleshwar	138.0	600	.00046	22°09'	75°39'
7.	Garudeshwar	10.0	500	.0001	21°50'	73°58'

Daily gauge and discharge data and hourly gauge data were available at National Institute of Hydrology. The daily gauge and discharge availability is shown in Table 2. The availability of hourly gauge data for the gauging sites listed in Table 1 are given in Table 3.

The information from the toposheets available at National Institute of Hydrology and Earth Science Department, University of Roorkee has been used in the study.

Table 2:Availability of daily gauge and discharge data for the gauging sites of the river Narmada

No	Name of the gauging site	Period
1	Manot	Aug. 1948 - Mar. 1953 Jul. 1968 - Oct. 1968 June 1970 - Oct. 1970 June 1980 - Sept. 1980
2	Jamtara	Jan. 1949 - Dec. 1967 June 1978 - Oct. 1978 June 1980 - Oct. 1980
3	Bermanghat	June 1980 - Oct. 1980 Jan. 1971 - Dec. 1978
4	Hoshangabad	Jul. 1968 - Sep. 1968 June 1980 - Oct. 1980
5	Mortakka	Jan. 1975 - Dec. 1977 Jan. 1978 - Mar. 1978 June 1978 - Oct. 1978
6	Mandeleshwar	Nov. 1971 - Oct. 1978 June-Oct. 1979-1980
7	Garudeshwar	Jan. 1948 - Dec. 1979

Table 3: Availability of hourly stage data for the gauging sites of the river Narmada

No	Name of the site	Period of availability
1	Manot	Jul. 1978 - Oct. 1978 Jan.-Oct. 1979 June -Oct. 1980
2	Jamtara	June-Oct. 1971-1980
3	Bermanghat	June-Oct. 1974-1980
4	Hoshangabad	Jan. 1959 - Dec. 1959 Jan. 1961 - Dec. 1965 Jan. 1968 - Dec. 1980
5	Mortakka	Aug. 1968 - Sep. 1968 June - Oct. for 1970-1980
6	Mandleshwar	June - Oct. for 1973-1980
7	Garudeshwar	Jan. 1969 - Dec. 1980

6.0 PROCESSING OF DATA

6.1 Rating Curve

Establishing a stage-discharge relation for various sites were carried out using daily stage and discharge data. They are given in a report of NIH, CS-6 (1985). A relationship of the form $Q = a(G - e)^b$ where, G, Q are stage and discharge respectively and a, b, e are parameters defining the relation. The established parameters are given in Table 4.

Table 4: Parameters defining the rating curves for the gauging sites of the river Narmada

No	Site	Parameters			Datum (m)
		a	b	c	
1	Manot	99.467	1.769	0.5	86.0
2	Jamtara	85.467	1.795	2.3	360.0
3	Bermanghat	96.428	1.73	4.0	306.0
4	Hoshangabad	173.183	1.858	1.9	282.0
5	Mortakka	605.09	1.54	2.6	150.0
6	Mandleshwar	331.209	1.715	0.9	138.0
7	Garudeshwar	250.0	1.66	1.7	12.0

6.2 Plan Area

Toposheets of scale (1:50000) are used in this study. The river and the associated contour curves were traced on to a sheet. These contours are at 20 m interval. Two contours were included in the analysis. The river is then divided into subreaches. The normal length of the sub-reach is 500 m.

However, it also varies betweeen 500 m to 1200 m. The width of the river, and the distance between the contours were measured. For a given discharge Q the stage was computed using the rating curve for the site Mortakka. This level was reduced by bed level drop when computations proceded to downstream reaches. These computations include interpolation of width for the corresponding stage and computing the plan area. The river reach between Mortakka to Garudeshwar was divided into 419 sub-reaches.

7.0 ANALYSIS AND RESULTS

A computer programme given in appendix 1 ALFA. FOR was developed to carry out these computations. The measured width and length of the subreaches given in Table 5 formed a part of the input data. The other input data include rating curve parameters, slope and the desired discharge. The output from the programme is the routing parameter x. This parameter has been found out for various discharges and a plot was made as shown in Figure 5.

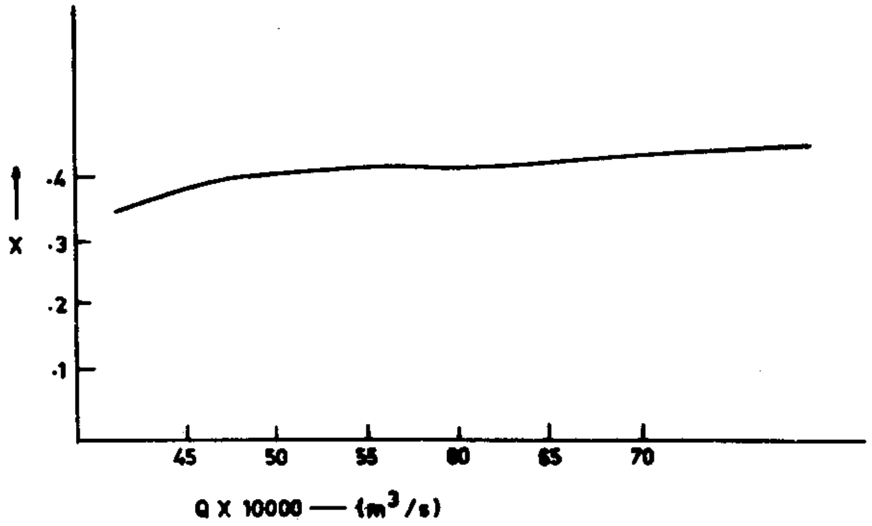


FIG.5 Variation of parameter 'x' with discharge 'Q'

From the figure 5, it can be seen that the value of 'x' varies between .32 to .42 for discharges 45000 Cumecs to 70000 Cumecs.

These x values formed an input to the programme MCM.FOR. Flood hydrographs observed at Mortakka in the year 1978 and 1979 are used to route them upto Garudeshwar. The necessary 'x' values are extrapolated and used. The travel time is deduced from the plotted hydrograph.

In the routing of flood hydrograph through a river reach such as between Mortakka and Garudeshwar, lateral flow is quite significant. In the present study the lateral flow has been considered by accounting for its effect at both upstream and downstream ends of the reach. The total lateral flow volume has been computed as difference between the observed upstream and downstream hydrographs for a flood event. The half of lateral flow volume has been added to the inflow hydrograph volume by taking the time distribution proportionate to that for inflow hydrograph. The modified inflow hydrograph is then routed through the reach to the downstream end using Muskingum-Cunge procedure. The remaining 50% lateral flow volume has been added to the routed outflow hydrograph considering its time distribution as proportionate to that for the routed hydrograph. This procedure of considering lateral flow though arbitrary, has provided satisfactory reproduction of observed hydrographs. It may, however, be necessary to appropriately modify such assumption in case

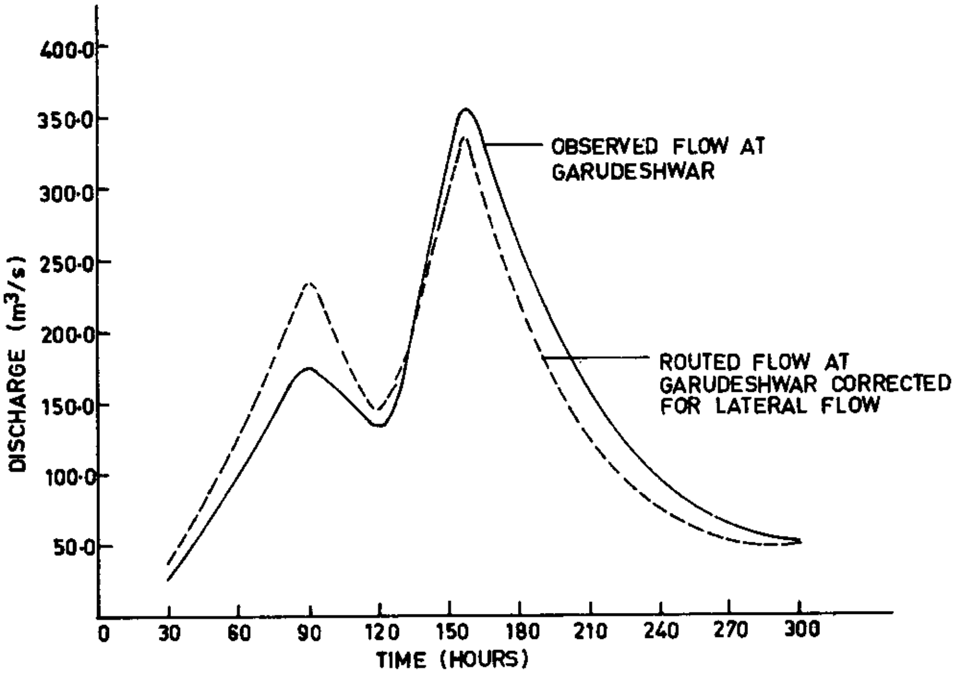


FIG.6 Observed and routed hydrograph at Garudeshwar for the 1978

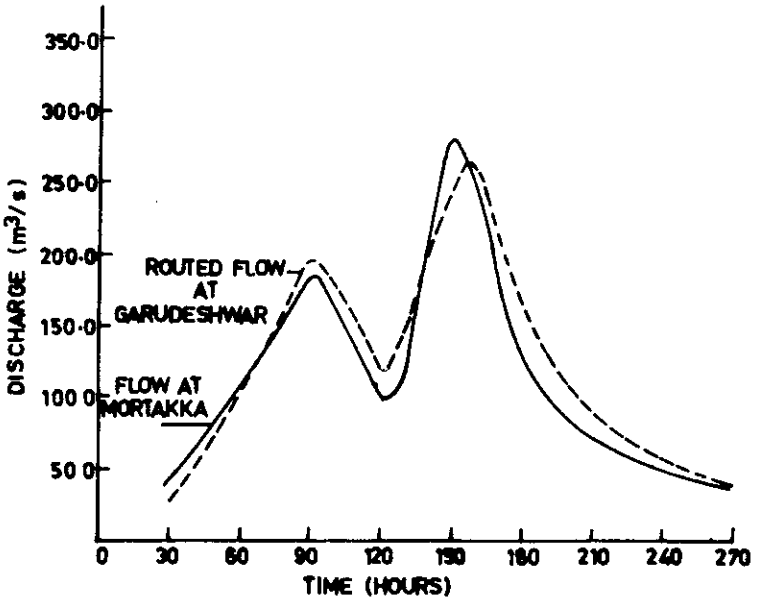


FIG.7 Upstream and routed hydrograph for the year 1978

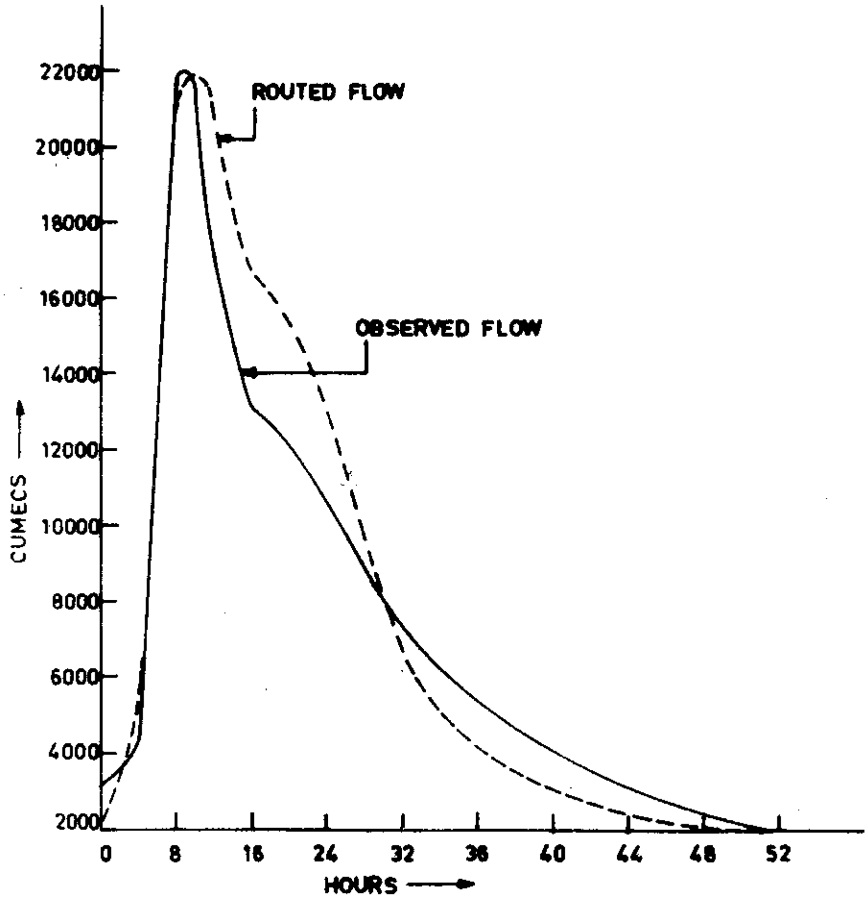


FIG.8 Observed and routed hydrograph at Garudeshwar for the year 1979

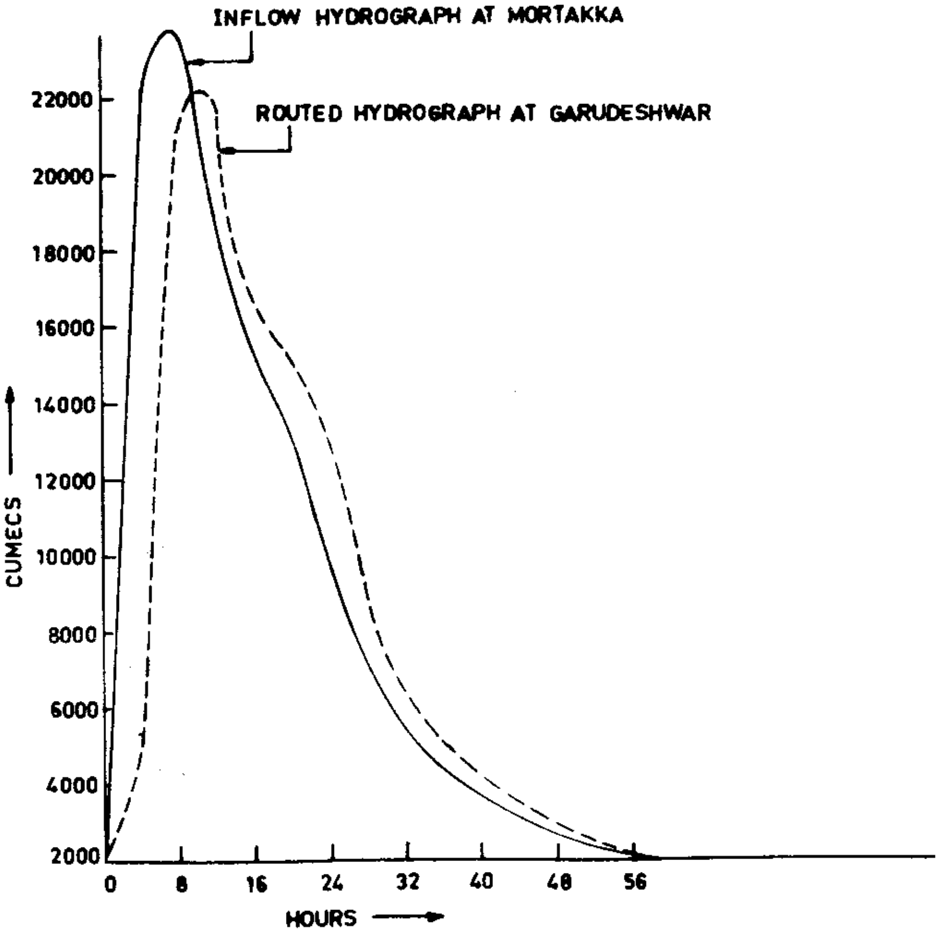


FIG.9 Upstream and routed hydrograph for the year 1979

of typical river reaches.

The Fig. 6 shows the upstream/inflow hydrograph observed) at Mortakka including the 50% of the lateral flow and the downstream routed hydrograph at Garudeshwar (not including 50% lateral flow). In fig. 7, the observed downstream hydrograph at Garudeshwar for the year 1978 has been compared with the routed hydrograph (including 50% lateral flow for the reach). It is seen that the routed hydrograph nearly matches the higher peak of the observed hydrograph though it is somewhat overpredicting the lower peak. This seems to be due to distribution of the lateral flow volume throughout all the ordinates of the hydrograph.

The Figures 8 & 9, show the corresponding results for the flood hydrograph of the year 1979 for Mortakka to Garudeshwar reach of river Narmada. As shown in Figure 9, the observed and routed flood hydrographs at Garudeshwar nearly match inspite of simplified assumption for the lateral flow distribution. The peaks of the two hydrographs are almost same, though in the recession portion the routed hydrograph overpredicts for some ordinates immediately after the peak.

REFERENCES

1. Miller, W.A. and Yevjenich, V.(1975), 'Unsteady flow in open channels'. Bibliography, Vol. III, Water Resources Publications, Fort Collins, Colorado.
2. Singh, V.P. and McCann, R.C.(1980), 'Some notes on Muskingum method of flood routing', Journal of Hydrology, Vol.48, No.3, pp 343-361.
3. Cunge, J.A.(1969), 'On the subject of a flood propagation computation method (Muskingum Method)', Journal of Hydraulic Research, Vol. 7, No.2, pp 205-230.
4. Hyami, S.(1951), 'On the propagation of flood waves', Bulletin No.1, Disaster Prevention Research Institute, Kyoto University, Japan.
5. Price, R.K.(1973), 'Flood routing in natural rivers', Proc. of the Institution of Civil Engineers 55, 913-930.
6. NERC (1975), 'Flood studies report', Vol.III, London.
7. Henderson, F.M. (1966), 'Open channel flow', MacMillian and Company, New York, P-364.
8. N.I.H., (1985), 'Rating curves for gauging sites on Narmada river', Report CS-6.

APPENDIX I

ALFA.FOR

```
C       Programme for ALFA
        DIMENSION W200(200),W180(200),WI(200)
        OPEN(UNIT=1,FILE='ALFA.DAT',STATUS='OLD')
        OPEN(UNIT=2,FILE='ALFA.RES',STATUS='NEW')
C       WRITE(2,99)
        READ(1,*) NSET,Q
        JP=0
        RIL=0.0
        SIG1=0.0
        SIG2=0.0
        DO 30 IJK=1,NSET
        RIL=0.0
        SIG1=0.0
        SIG2=0.0
        READ(1,*) SLOP,DX,NX,COU,ARC,ERC,BRC,REL
        READ(1,*) (WI(I),W200(I),W180(I),I=1,NX)
        BRC=BRC-SLOP*REL
        DXSM=DX*SLOP*SLOP*1000.
        S13=SLOP**(1./3.)
        EL=(Q/ARC)**(1./ERC)+BRC
        DO 20 J=1,NX
        JP=JP+1
        EL=EL-DX*SLOP
        W=((W200(J)-W180(J))/20.)*(EL-COU)+W180(J)
        IF(W.LT.WI(J))W=WI(J)
        A= DX*W/1000.
        A2LS2=A*A/DXSM
        SIG1=SIG1+A2LS2
        AS13=A/S13
        RIL=RIL+DX/1000.
        SIG2=SIG2+AS13
20      CONTINUE
        ALFA=0.5*((SIG2/RIL)**-3.)*SIG1
        WRITE(2,999) ALFA,Q,RIL
        EPCI=0.5-(ALFA*Q)/(RIL*RIL* 3.)
        WRITE(2,99)ALFA,RIL,EPCI
30      CONTINUE
9       FORMAT(1X,I5,2F10.2,1X,F10.4,1x,2F10.4)
99      FORMAT(6X,'THE Alfa is..',f10.4,'for reach..',f10.4,
        17X,'x is....',f10.4)
999     FORMAT(1X,'..............The Attenuation Parameter'
        1,5x,'is......',F10.5,'FOR Q...',F10.1,'FOR REACH',F10.1)
        STOP
        END
```

TABLE 5:INPUT DATA FOR ALFA.FOR

```
6  45000.
.000526 500.  119  180. 605. 1.54 155.6 -59500.
               0.2250    0.3000    0.3000
               0.3750    0.4000    0.4000
               0.3500    0.6500    0.5500
               0.4000    0.5500    0.5000
               0.3500    0.7000    0.4000
               0.3250    0.4300    0.3500
               0.3250    0.5000    0.3500
               0.4000    0.5500    0.4000
               0.3500    1.0500    0.5000
               0.4250    0.6000    0.5000
               0.4500    0.7000    0.6000
               0.5000    0.7500    0.5000
               0.5000    1.0000    0.7500
               0.5000    1.2500    0.6000
               0.4250    0.6500    0.5500
               0.4250    0.5500    0.5000
               0.4500    0.6000    0.8000
               0.4500    0.9500    0.6000
               0.4500    1.1500    0.5000
               0.4000    1.1000    0.4500
               0.4250    1.0500    0.4500
               0.4500    1.6000    0.5000
               0.4500    1.3500    0.5500
               0.4500    1.4500    0.5000
               0.3700    0.5000    1.1500
               0.4750    0.6000    0.4000
               0.4000    0.5000    0.2500
               0.2000    0.8500    0.2500
               0.1500    0.9500    0.4000
               0.4000    1.6000    0.5000
               0.3000    2.1000    0.5000
               0.3500    2.7000    0.6000
               0.6250    3.6000    0.5000
               0.5200    2.8000    0.4500
               0.4500    3.1000    0.4500
               0.4500    1.4500    0.4000
               0.3000    1.1000    0.3000
               0.2500    0.4000    0.3000
               0.2500    0.5000    0.3000
               0.2250    0.3000    0.3000
               0.4000    0.5500    0.4000
               0.3000    0.6000    0.3000
               0.2500    0.4500    0.2500
               0.3000    0.7500    0.6000
               0.2500    1.2500    0.4500
               0.3000    1.7500    0.3500
               0.2500    3.5000    0.8000
               0.2500    3.7000    1.1000
               0.3500    5.7500    1.4000
               0.3500    7.4000    1.5000
               0.4500    7.4000    1.7000
               0.6000    8.0000    1.8000
               0.6000   10.6000    1.9000
               0.6500    7.2000    1.7000
               0.2250    7.2500    1.5000
               0.2000    0.4000    0.3000
               0.3000    0.6000    0.4000
               0.3000    0.6500    0.5500
               0.2500    0.5500    0.5000
               0.3000    0.7000    0.4000
               0.2750    0.4250    0.3500
               0.2500    0.5000    0.3500
               0.3000    0.5500    0.4000
```

```
            0.3000    1.0500    0.5000
            0.3000    0.6000    0.5000
            0.3000    0.7000    0.6000
            0.3000    0.7500    0.5000
            0.3700    1.0000    0.7500
            0.3250    1.2500    0.3000
            0.3000    0.6500    0.2750
            0.4000    0.5500    0.2500
            0.5000    0.6000    0.2500
            0.4500    0.9500    0.4000
            0.4500    1.1500    0.3000
            0.5000    1.1000    0.2500
            0.5000    1.0500    0.2250
            0.4000    1.6000    0.2250
            0.3500    1.3500    0.2500
            0.3700    1.4500    0.5500
            0.3800    0.5000    0.5000
            0.3000    0.4000    0.3000
            0.3500    0.5000    0.4000
            0.1250    0.8500    0.7500
            0.2000    0.9500    0.2500
            0.3000    1.6000    0.4000
            0.3000    2.1000    0.5000
            0.3500    2.7000    0.4000
            0.4000    3.6000    0.6000
            0.4000    2.8500    0.5000
            0.4000    3.1000    0.4500
            0.3500    0.6500    0.4500
            0.2000    1.4500    0.4000
            0.2000    1.1000    0.3000
            0.2500    0.4000    0.3000
            0.2700    0.3500    0.3000
            0.3000    0.4000    0.3000
            0.2750    0.5000    0.4000
            0.2000    0.3500    0.3000
            0.3500    0.5500    0.2500
            0.4000    0.6000    0.3000
            0.3000    0.4500    0.3000
            0.5000    0.7500    0.3500
            0.2750    1.3000    1.2500
            0.4000    1.7500    0.3500
            0.5000    3.5000    0.9000
            0.7000    3.7000    1.1000
            0.6000    5.5250    1.4000
            0.6500    7.4000    1.5000
            0.7000    7.4000    1.7500
            0.8000    8.0000    1.8500
            0.7000   10.6000    1.9000
            0.6000    7.2000    1.7000
            0.5000    7.2500    1.5500
            0.5500    5.0500    3.1000
            0.5000   10.0000    2.0600
            0.4000   14.9000    1.8500
            0.5500   12.0000    1.9200
            0.6000   20.0000    1.6000
            0.7000   23.0000    1.7200
.000526 10000. 1 160. 605. 1.54 155.6 0.0
            0.5       0.9        .6
.000528 500.  51  160. 551. 1.37 139.8 0.0
            0.6000   12.7500    5.0000
            0.6500   14.3500    5.2500
            0.6000   15.1000    3.2000
            0.6500   16.2500    2.5000
            0.5500   14.2000    2.1500
            0.5500   12.5000    2.5000
```

```
          0.5000   11.2500    2.0000
          0.6500   12.1000    2.0000
          0.7000   12.6000    1.2500
          0.7000   13.0000    1.1000
          0.7000   15.0000    1.4000
          0.6000   14.5000    1.2500
          0.5000   16.0000    1.5500
          0.5000   15.7000    1.4000
          0.4500   16.1000    1.2500
          0.4500   15.5000    1.7500
          0.5500   16.7000    1.6000
          0.6500   17.0000    2.1000
          0.7000   17.0000    2.7500
          0.8000   18.0000    3.0000
          0.7500   23.0000    3.5000
          0.7000   20.0000    4.5000
          0.6500   20.0000    8.0500
          0.7000   23.0000    8.0000
          0.7500   20.0000    8.5000
          0.8000   20.0000    8.7500
          1.2500   25.0000    8.4000
          1.2000   25.0000    9.0000
          1.1000   18.0000   12.5000
          1.0500   17.5000   13.0000
          1.0500   16.5000   12.5000
          1.0000   14.0000   12.5000
          1.1500   13.5000    9.5000
          0.9500   13.7500    8.4000
          0.9000   13.0000    8.0000
          0.8000   15.7000    4.7000
          0.7500   15.5000    4.5000
          1.0000   14.0000    4.5000
          1.0000   14.5000    5.0000
          0.7000   15.0000    5.5000
          0.7000   16.5000    8.0000
          0.7000   16.0000    7.2500
          0.5500   20.0000    7.0000
          0.5500   16.5000    9.2500
          0.5000   16.5000    9.1000
          0.6000   16.6000    9.1000
          0.6500   17.6000    7.9000
          0.6000   17.7000    7.6000
          0.9000   15.0000    7.7500
          0.7000   14.7000    7.2500
          0.6500   15.0000    8.0000
.000510 500.  192  140. 551. 1.37 139.8 25500.
          0.6000   11.0000    1.1000
          0.4500   11.5000    0.9500
          0.5250   12.0000    0.5350
          0.6000   11.0000    0.5400
          0.6000   11.0000    0.6200
          0.7500   14.0000    0.8700
          0.7500   15.0000    1.4100
          0.7000   13.0000    1.0000
          0.6000   12.0000    1.3500
          0.6000   12.0000    2.4000
          0.6000   11.0000    1.1600
          0.6500   11.0000    1.6500
          0.6500    6.0000    2.6500
          0.6400    6.0000    3.0000
          0.6200    6.5000    2.0200
          0.6000    7.5000    1.3200
          0.6100    8.0000    1.3000
          0.6500    9.5000    1.2000
          0.6500    9.5000    1.7500
```

```
0.7400   12.0000    1.2600
0.7500   12.0000    1.2200
0.7500   12.0000    1.6000
0.7500   11.5000    1.5000
0.6500   11.5000    1.4500
0.7500   11.5000    3.9000
0.9000   10.5000    1.9000
0.9000   11.0000    1.9000
0.9500   11.2500    1.5000
1.0000   11.5000    1.0700
1.0000   10.5000    1.4500
1.0000   10.5000    1.0700
1.0000   11.0000    1.3500
1.0000   12.0000    1.3500
0.5000   13.0000    1.0500
1.0000   15.0000    1.3500
0.8500   10.5000    3.2500
0.7500   10.5000    3.2000
0.6500   11.2000    2.4500
0.6500   11.0000    2.0500
0.6300   12.5000    2.9300
0.6000   12.6000    2.3000
0.6000   12.5000    2.2000
0.6000   12.0000    2.1000
0.6000   11.0000    1.6000
0.6000   11.0000    1.3000
0.6000    9.5000    1.1000
0.6000    9.0000    1.2000
0.6000    9.5000    1.2000
0.7000   10.0000    1.3000
0.7000   11.5000    1.4000
0.7500   11.5000    1.2000
0.7500   12.1000    1.4500
0.8000   15.0000    3.5000
0.7500   14.9000    3.2000
0.6500   14.7500    3.3000
0.7500   14.3000    3.6000
0.7000   14.1000    2.1000
0.6000   14.2000    1.5000
0.7000   15.3000    1.7000
0.6500   14.3000    1.5000
0.7500   12.5000    1.5500
0.7000   12.7500    1.8000
0.7000   13.0000    1.1000
0.7000   13.5000    2.7500
0.7000   11.1000    2.5000
0.6500   11.0500    1.5000
0.6500   10.8000    1.2500
0.8000   10.7000    1.1000
0.7500   11.2500    1.2000
0.7000   11.3000    1.1000
0.7500   10.7500    1.1000
0.7000   12.5000    2.0000
0.6000  13.0000    1.5500
0.6000   13.1000    1.8000
0.7000   12.9000    3.2000
0.7000   12.3000    3.0000
0.7000   12.6000    3.3000
0.8000   12.3000    3.3000
0.8000   11.7500    3.3000
0.8000   11.5000    3.1500
0.7000   11.9000    3.5000
0.7500   12.0000    3.2000
0.7500   11.5000    3.0500
0.8000   12.0000    3.0000
```

0.7000	12.1000	3.0000
0.7000	14.1000	2.8000
0.6500	13.5000	5.8000
0.7500	14.5000	5.3000
0.7000	14.2500	4.7500
0.7000	15.7000	4.0000
0.5500	16.0000	3.6000
0.5500	16.2000	4.0000
0.6000	15.7000	2.3000
0.6500	15.0000	2.1000
0.8000	14.1000	4.5000
0.7500	14.7000	3.0000
0.7500	14.0000	4.5000
0.6500	14.5000	3.8000
0.8000	16.7500	2.8000
0.8000	16.3000	3.2000
0.6000	12.0000	2.0000
0.6000	11.7000	1.3000
0.5500	10.7000	1.4000
0.7000	4.2500	2.2500
0.6000	4.6500	2.5500
0.6000	4.6500	2.5000
0.6000	5.0500	2.4000
0.7000	5.5000	2.4500
0.6000	5.5000	1.4500
0.5500	5.5500	1.4000
0.6000	4.8000	2.2000
0.6500	4.3500	2.2500
0.6500	4.3500	1.8500
0.5000	2.9000	1.7500
0.6500	3.7500	1.8500
0.6500	3.6500	1.7500
0.4000	3.5000	1.4000
0.4000	3.5000	1.6500
0.4500	3.5500	1.5500
0.5000	3.6000	3.3000
0.5200	3.6200	0.6200
0.5000	3.6000	0.6000
0.5000	3.5000	0.6000
0.5500	0.8000	0.6500
0.6000	0.9000	0.7000
0.6000	0.9000	0.7000
0.5000	0.7500	0.6000
0.5500	16.5000	0.6500
0.4800	15.8000	0.5800
0.4500	15.5000	0.5500
0.4500	0.6500	0.5500
0.4000	0.6000	0.5000
0.4500	0.6500	0.5500
0.4500	0.6100	0.5500
0.4100	0.6100	0.5100
0.4500	0.6500	0.6500
0.5000	0.7000	0.6000
0.4500	0.6500	0.5000
0.5000	0.7000	0.6000
0.5000	0.7000	0.6000
0.4000	0.6000	0.5000
0.4500	0.6500	0.5500
0.4500	0.6500	0.5500
0.4500	0.6500	0.5500
0.4000	0.6000	0.5000
0.4500	0.6500	0.4500
0.4000	0.6000	0.5000
0.4000	0.6000	0.5000
0.4000	0.6000	0.5000

```
                 0.4500    0.6500    0.5500
                 0.5000    0.7000    0.6000
                 0.5000    0.7000    0.6000
                 0.5000    0.7000    0.6000
                 0.5000    0.7000    0.6000
                 0.5500    0.7500    0.6500
                 0.6000    0.8000    0.7000
                 0.6500    0.8500    0.7500
                 0.6000    0.8000    0.7000
                 0.6000    0.8000    0.7000
                 0.5500    0.7500    0.6500
                 0.6000    0.8000    0.7000
                 0.6000    0.8000    0.7000
                 0.6000    0.8000    0.7000
                 0.6000    0.8000    0.7000
                 0.2000    1.5000    0.8000
                 0.1500    1.0000    0.8500
                 0.3000    1.0000    0.9000
                 0.4000    1.1000    0.9500
                 0.3000    1.0500    0.9000
                 0.3500    1.2000    1.0000
                 0.4500    3.6000    1.7000
                 0.3500    7.0000    2.0000
                 0.3500    8.0000    2.1000
                 0.2000    7.0000    0.5300
                 0.3000    1.7500    0.8000
                 0.2500    0.8000    0.6000
                 0.2000    0.8000    0.8000
                 0.3500    0.9000    0.9000
                 0.3000    0.8500    0.8000
                 0.3500    1.0500    0.9000
                 0.4000    0.9500    0.7500
                 0.3000    0.8000    0.7000
                 0.3500    0.8500    0.7500
                 0.3000    0.7500    0.6500
                 0.3500    1.0500    0.8500
                 0.2300    1.5000    1.4000
                 0.2000    1.7000    1.1000
                 0.1000    0.8000    0.8000
                 0.2000    0.8500    1.0000
                 0.1000    1.2000    0.7500
                 0.0500    1.2000    1.0000
                 0.1000    1.7500    1.1000
.000525 10000. 3 140. 551 1.37 139.8 121500.
                  .35       .5        .4
                  .15       .3        .25
                  .4        .5        .45
.000526 500.  54  100. 551. 1.37 139.8 151500.
                 0.5000    1.5000    0.5500
                 0.5500    1.0000    0.7000
                 0.7000    1.4000    1.2500
                 0.7000    1.2500    0.9500
                 0.6500    1.1000    0.9500
                 0.6500    1.3000    1.0500
                 0.7000    1.6000    1.3000
                 0.6500    2.5000    1.8000
                 0.6500    1.6000    1.2000
                 0.5000    1.5000    0.8000
                 0.5500    1.0000    0.9000
                 0.6000    1.1000    1.0500
                 0.7000    1.2000    0.8000
                 0.6000    0.9500    0.8000
                 0.6000    1.3000    1.0000
                 0.5500    1.0500    0.8000
                 0.4500    1.0000    0.8000
```

```
0.3500    1.6000    0.7500
0.5000    1.0000    0.7000
0.6000    2.5000    1.1000
0.5500    1.1500    0.7500
0.5500    1.6000    0.9000
0.5500    1.7000    1.8000
0.6000    1.7500    1.2500
0.6000    1.8000    1.5000
0.6500    3.3500    3.0000
0.4500    2.1000    2.0000
0.4000    1.2000    1.0000
0.5500    1.0500    1.0000
0.6500    0.8000    0.7000
0.6000    1.0500    0.8000
0.5500    0.9500    1.0000
0.5500    1.5000    0.9000
0.5500    1.6000    1.2500
0.5000    1.9000    1.2500
0.5000    2.6000    1.4000
0.5500    2.5000    1.4000
0.5500    2.2500    0.9000
0.5500    2.1500    1.9000
0.6000    1.7500    1.9500
0.5000    2.1000    1.1000
0.4500    2.6000    1.2000
0.6000    2.7000    1.5500
0.7000    2.8000    2.4000
0.6500    2.3000    1.4000
0.6000    2.2000    1.1000
0.6000    2.0000    2.1000
0.5000    2.1000    1.3000
0.6000    1.9000    1.5000
0.5500    1.8500    1.2000
0.6000    1.3500    1.1000
0.5500    1.6000    1.2000
0.5500    1.5000    1.7500
0.5500    1.4000    1.7000
```

MMC.FOR

```
C
      REAL Q1(500),Q2(500),X(500)
      DIMENSION TIME(500),QEST(500),QUP(500),QDNP(500)
      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,AP,WSP,QCON,QDNS(500),TDEVN
      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
      DX=DXLR/FLOAT(JX-1)
      DK=DX/WSP
      EPSILO=.5*(1.-QCON*AP*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
      JXM1=JX-1
      T=0.0
      DEVN=0.0
      TOTDIS=0.0
      TOTD=0.0
      QP1=QINIT
      QP2=QINIT
      QDNP2=QINIT
      QDNP1=QINIT
      QDN=QINIT
      QTOT=0.0
      JCOUNT=0
      ICOUNT=0
      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
      Q1(1)=QHYDRO(L)
      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)
      IF(TH.LT.TDEVN) GO TO 8
      DEVN=DEVN+(Q1(JX)-QDN)*(Q1(JX)-QDN)
      ICOUNT=ICOUNT+1
      JCOUNT=JCOUNT+1
      IF(JCOUNT.NE.2) GO TO 8
      TOTD=TOTD+2.*DT*(Q1(JX)+QP1+QP2)/3.
      TOTDIS=TOTDIS+2.*DT*(QDN+QDNP1+QDNP2)/3.
      JCOUNT=0
8     WRITE(33,302) TH,X(JX),Q1(JX),QDN
302   FORMAT((20X,F6.2,9X,F8.1,2(8X,F9.2)))
      WRITE(33,303)
303   FORMAT(1H,/)
14    CONTINUE
      TOTDIS=TOTDIS/((TH-TDEVN)*3600.)
      TOTD=TOTD/((TH-TDEVN)*3600.)
      DISDIF=(1.-TOTD/TOTDIS)*100.
      DEVN=SQRT(DEVN/FLOAT(ICOUNT))*100./TOTDIS
      WRITE(33,304) TOTDIS,DISDIF,DEVN
304   FORMAT(30H AVERAGE RECORDED DISCHARGE = ,F10.2,
      19H   CUMECS/
      252H DIFFERENCE BETWEEN RECORDED AND PREDICTED AVERAGE D
      311HISCHARGE = ,F6.2,1H%/
      424H    STANDARD DEVIATION = ,F6.2,1H%//)
      WRITE(32,186)
186   FORMAT(10X,'MUSKINGUM CUNGE METHOD OF FLOOD ROUTING'/
      1 10X,'PLOT SHOWS ESTIMATED AND MEASURED Q-HYDROGRAPH'/
      210X,'AND HYDROGRAPHS AT BOTH END OF THE REACH'/)
      CALL PLOT (QEST,TIME,LEND,QDNP)
      CALL PLOT (QEST,TIME,LEND,QUP)
      QQQ=0.0
      QQ1=0.0
      DO 127 I=1,LEND
```

```
      QQQ=QQQ+QDNP(I)
127   QQ1=QQ1+QHYDRO(I)
      DIFF=QQQ-QQ1
      DIFF=1.-DIFF/QQQ
      DO 128 I=1,LEND
128   QDNP(I)=QDNP(I)*DIFF
      CALL PLOT (QUP,TIME,LEND,QDNP)
      CALL PLOT (QEST,TIME,LEND,QDNP)
      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,AP,WSP,QCON,
     3QDNS(200),TDEVN
      COMMON IQH,IQDNS
      READ(3,300)( TITLE(I),I=1,60)
      READ(3,*) JX,LEND,IQH,IQDNS
      READ(3,*)DXLR,DT,DTHYD,QINIT,WSP,AP,QCON,TDEVN
      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,AP,QCON,TDEVN
302   FORMAT(20X,F9.2,F7.1,F4.1,F6.2,F8.6,F9.3,2F6.1,F5.2,E9.3,F7.2,F6.2)
      READ(3,*) (QHYDRO(I),I=1,IQH)
      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)
      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',I3,10(6X,I4),4X,'Q HR','  QEST'/)
         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),I,(A(J),J=1,81),CUSEC(I),QEST(I)
14       FORMAT(1X,F6.1,1X,I4,81A1,F9.3,F9.2)
         DO 15 I=1,81
15       A(I)=BLANK
         K=1
         KC=7
         DO 20 I=2,N
         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),K,(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),K,(A(J),J=1,81),CUSEC(I),QEST(I)
27      DO 28 J=1,81
28      A(J)=BLANK
29      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
```

TABLE 6: INPUT DATA FOR MMC.FOR

```
Routing of flood between Mortakka and Garudeshwar of the river Narmada
      3        62       62       62
295300.0       10800    10800    2200     6.5      981800. 30000.  3600.
2234.9         2557.5   6007.9   9187.    16333.   22283.   24124.   26715.   26189.   23955.
20655.4        18388.   16954.   16333.   16038.   16038.   16038.   15745.   15309.   14124.
13942.         13331.   12649.   11714.   10803.   9898.    8994.    8354.    7595.    6949.
6302.          5759.    5434.    5136.    4959.    4785.    4632.    4368.    3965.    3840.
3716.          3593.    3472.    3353.    3231.    3101.    2921.    2809.    2761.    2620.
2527.          2460.    2450.    2300.    2226.    2182.    2080.    2124.    2109.    2052.
1981.          1835.
6502.          6487.    6502.    6731.    7293.    8103.    30038.   37076.   41033.   42207.
41664.         38265.   35187.   31956    30541.   26770.   25348.   24572.   24060.   23633.
23249.         22673.   21932.   21199.   20500.   19504.   18736.   17958.   17193.   16616.
15616.         14935.   14274.   13528.   12944.   12430.   11925.   11579.   11182.   10827.
10531.         10148.   9873.    9417.    9155.    8965.    8759.    8454.    8071.    7890.
7662.          7501.    7341.    7120.    6949.    6808.    6639.    6472.    6366.    6246.
6083.  5995.
0.0
```

8.0 CONCLUSIONS

The successful use of this method requires the flood records including the map showing flood inundation. Here the use of established rating curves are attempted to compute the area of inundation. The use of this method is thus limited to the extend of the applicability of these rating curves. Further, the water surface slope is assumed to be the same as that of bed slope while computing the plan area. In the absence of observed data to prepare inundation map, this method can be justified. Another assumption made in these computations is that the shore on either side of the flow follow the pattern of the contours i.e. similar variation in the longitudinal direction.

It can be seen that the routed hydrograph nearly matches the observed hydrograph at Garudeshwar. The results shown in figures 6 through 9 support the use of the Muskingum Cunge method of flood routing. Further studies are needed to establish the relation discharge and attenuation parameter/ routing parameter, before this method can be put to use in Indian rivers.

Furthermore in case tributaries which are being gauged and flood hydrographs are available for such tributaries joining the main river within a river reach, the lateral flow could be considered by dividing the river reach into sub-reaches defined by junctions of the main river and tributaries. Studies with proper data base for consideration of lateral flow are also needed.