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Dam Break Analysis of Maithon and Panchet Dams and Inundation Mapping

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ABSTRACT: The failure of a dam is of serious concern due to involvement of loss of lives and properties. Dam break floods analysis is, therefore, important for flood disaster management. The commonly used computer programs for such analysis are NWS DAMBRK, MIKE and HEC series of models. These programs are capable of simulating the dam break flood wave and routing through river channels and downstream structures like bridges, embankments, etc. These programs can provide information about the flood inundation and warning time resulting from dam failures. The present paper analyses dam break flood simulation of Maithon and Panchet reservoir located in Damodar valley. The water resources of the Damodar valley have been trapped by construction of series of reservoirs on Damodar river and its tributaries. Panchet reservoir with gross storage capacity of 1358 MCM is located on Damodar river while Maithon reservoir with gross storage capacity of 1093 MCM is located on Barakar river, a tributary of Damodar. The two rivers join together at 6.4 km d/s of Panchet dam and 12.9 km d/s of Maithon dam. The model simulates the development of breach in the dam section and routs the resulting flow in the downstream river valley using one dimensional Saint-Venant equation. The failure of Maithon dam on Barakar river has been considered separately and its outflow at the confluence of two rivers has been considered as lateral inflow while simulating the dam break failure in Panchet dam over river Damodar. Four cases of failure scenarios has been analyzed: (i) failure of only Panchet dam, (ii) failure of only Maithon dam, (iii) failure of both Panchet and Maithon dams and (iv) none of the dams fail under probable maximum flood. The maximum discharge, maximum stage and maximum flow velocity and its time of occurrence at various cross sections along the Damodar and Barakar rivers have been computed. The inundation maps showing the extent, depth and area of inundation have been prepared in GIS environment for all four cases.

INTRODUCTION

The dam break floods analysis is important from the point of view of flood disaster management. The failure of a dam may cause catastrophe in the downstream reaches having dense population and important establishments. Dam Break Flood (DBF) analysis has become important not only for new dams but also for reviewing the existing dams designed and constructed many years ago utilizing the limited historical data and the present design standards may not be met. DAMBRK by U.S. National Weather Service, HEC RAS by U.S. Army Corps of Engineers and MIKE-11 by Danish Hydraulic Institute, Denmark are some of the many computer programs used to analyze such events. These programs are capable of simulating the DBF wave and routing through river channels and downstream structures like bridges, embankments, etc. These programs can provide information about the flood inundation and warning time resulting from dam failures. DAMBRK model uses Saint Venant's equations for routing dam break floods in channels. For reasons of simplicity, generality, wide applicability and uncertainty in the actual failure mechanism, this model allows the failure timing interval and terminal size and shape of breach as input. It gives the magnitude and occurrence-time of flooding in the downstream valley by routing the outflow hydrograph through the valley. The dynamic wave method based on the complete equations of unsteady flow is the appropriate technique to route the dam break flood hydrograph. The present paper discusses the use of NWS DAMBRK model for dam break flood simulation for Maithon and Panchet dams and preparation of flood inundation map.

METHODOLOGY

The Saint-Venant equations with additional terms for the effect of expansion/contraction, channel sinuosity and non-Newtonian flow are expressed as conservation of mass and momentum equations as given in Equation (1) and (2),

$$\frac{\partial Q}{\partial x}+\frac{\partial S_c(A+A_0)}{\partial t}-q=0 \quad \dots (1)$$

and,

$$\frac{\partial(S_m Q)}{\partial t}+\frac{\partial(\beta Q^2/A)}{\partial x}+gA\left(\frac{\partial h}{\partial x}+S_f+S_e+S_i\right)+L=0 \quad \dots (2)$$

where h is the water surface elevation, A is the active cross sectional area flow, A_o is the inactive (off-channel storage) cross sectional area. S_c and S_m are sinuosity factors which is a function of h, x is the longitudinal distance along the channel (valley), t is the time, q is the lateral inflow or outflow per linear distance along the channel (inflow is positive and outflow is negative in sign), β is the momentum coefficient for velocity distribution, g is the acceleration due to gravity, S_f is the boundary friction slope, S_e is the expansion-contraction slope and S_i is the additional friction slope associated with internal viscous dissipation of non-Newtonian fluids such as mud/debris flows.

In Equation (2), L is the momentum effect of lateral flow assumed to enter or exit perpendicular to the direction of the main flow. The boundary friction slope S_f in Equation (2) is evaluated for Manning's equation for uniform steady flow, i.e.

$$S_f = \frac{n^2 |Q| Q}{2.21 A^2 R^{4/3}} = |Q| Q / K^2 \qquad \ldots (3)$$

in which n is the Manning's coefficient of frictional resistance, R is the hydraulic radius and K is the conveyance factor. When the conveyance factor K is used to represent S_f, the valley/channel cross-sectional properties are designated as left floodplain, channel and right floodplain rather than as a composite channel/valley section. The conveyance factor is evaluated as follows,

$$K_l = \frac{1.49}{n_l} A_l R_l^{2/3} \qquad \ldots (4)$$

$$K_c = \frac{1.49}{n_c s_m^{1/2}} A_c R_c^{2/3} \qquad \ldots (5)$$

$$K_r = \frac{1.49}{n_r} A_r R_r^{2/3} \qquad \ldots (6)$$

$$K = K_l + K_c + K_r \qquad \ldots (7)$$

in which the subscripts l, c, and r represent left floodplain, channel and right floodplain respectively. The sinuosity factor S_c and S_m in Eqns. (1), (2) and (5) represent the weighted ratio of the flow path distance along the floodplains. They vary with depth of flow according to the following relations,

$$S_{c_j} = \frac{\sum_{k=2}^{k=j} \Delta A_{l_k} + \Delta A_{c_k} s_{c_k} + \Delta A_{r_k}}{A_{l_j} + A_{c_j} + A_{r_j}} \qquad \ldots (8)$$

$$S_{m_j} = \frac{\sum_{k=2}^{k=j} \Delta K_{l_k} + \Delta K_{c_k} s_{m_k} + \Delta K_{r_k}}{K_{l_j} + K_{c_j} + K_{r_j}} \qquad \ldots (9)$$

in which $\Delta A = A_{m+1} - A_m$ and the sinuosity factor S_m represents the sinuosity factor for a differential portion of the flow between the m^{th} depth and the $m+1^{th}$ depth. Distances between the cross sections are measured along the mean flow path for the floodplain flow. The momentum coefficient for velocity distribution β is evaluated as follows,

$$\beta = \frac{1.06\left(K_l^2 / A_l + K_c^2 / A_c + K_r^2 / A_r \right)}{(K_l + K_c + K_r)^2 / (A_l + A_c + A_r)} \qquad \ldots (10)$$

where β = 1.06 when floodplain characteristics are not specified and the total cross section is treated as a composite section.

The term S_e in Equation (2) is defined as follows,

$$S_e = \frac{k_{ce}\, \Delta (Q/A)^2}{2 g \Delta x} \qquad \ldots (11)$$

in which k_{ce} is the expansion-contraction coefficient and $\Delta(Q/A)^2$ is the difference in the term $(Q/A)^2$ at two adjacent cross sections separated by a distance Δx. A provision is made within DAMBRK to automatically change contraction to expansion coefficients and vice versa if flow direction changes from downstream to upstream in which case the computed Q values are negative.

The active cross-sectional area A and inactive (off-channel storage) area A_0 are obtained from hydrographic surveys and/or topography maps. These are specified as input to DAMBRK as a table of wetted top widths B which varies with elevation at selected cross sections along the channel/valley. Within the model, the top width table is integrated using the trapezoidal rule to obtain a table of cross-sectional area versus elevation. Linear interpolation is used for intermediate elevations between specified tabular points. Areas associated with elevation exceeding the maximum value as specified in the table are extrapolated.

The Manning roughness coefficient, n is specified for each reach between adjacent cross sections and varies with elevation according to user specified tabular values similar to the top widths table. Linear interpolation is used for value associated with intermediate elevations. Values for n for elevation exceeding the tabular elevations are not extrapolated rather they are assigned the value associated with the maximum elevation.

STUDY AREA

The two dams Maithon and Panchet are located on two rivers namely, Barakar and Damodar. Barakar is a left tributary of Damodar river and meets it, after flowing for a distance of 12.75 km from Maithon dam site, at a distance of 5.8 km downstream of Panchet dam. Both the dams are earthen dam and are located in Dhanbad district of Jharkhand state. The schematic diagram of location of two dams are given in Figure 1. The gross capacity of maithon reservoir is 1093.54 MM^3 at FRL of 152.40 m while that of Panchet reservoir is 1358.08 MM^3 at 135.64 m.

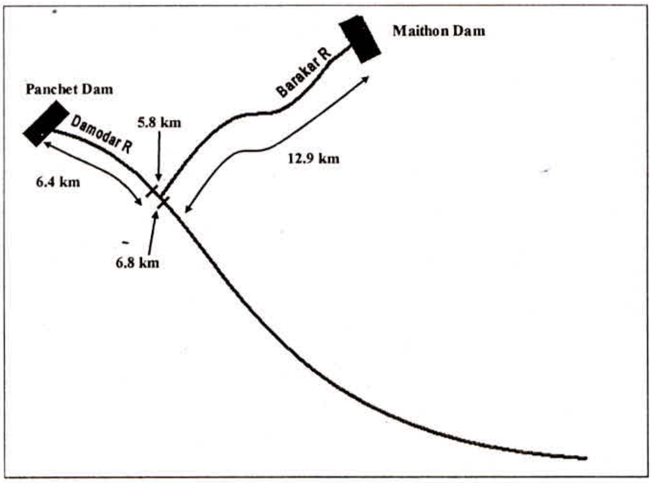

Fig. 1: Schematic diagram of river system and location of dams

ANALYSIS AND DISCUSSIONS

For dam break analysis the reservoir inflow has been assumed based on a recently published paper in which the PMF have been estimated using unit hydrograph and PMP approach (Banerjee *et al.*, 2003). The flood hydrograph for Maithon and Panchet dam site is shown in Table 1 and 2 respectively and have been used in simulation of dam break flood. The various combination of failure scenario of two dams have been simulated. For preparation of inundation map due to flood generated from dams break the digital elevation model (DEM) of the downstream has been prepared using Survey of India toposheets available in 1: 25,000 and 1:50,000 scale. The river cross sections along the Barakar and Panchet rivers have been collected from Damodar Valley Corporation and have been used in the study. The river cross sections at 10 locations at chainage 3.35, 5.35, 5.75, 6.15, 6.95, 7.75, 8.55, 9.35, 10.15 and 11.35 km have been used along Barakar river. Along Damodar river, cross sections at chainage 0.3, 0.45, 0.75, 1.55, 2.35, 3.35, 5.8, 6.8, 7.4, 8.15, 8.95, 11.75, 13.35, 15.75, 18.85, 19.65, 20.55, 21.95, 23.35, 24.95, 32.15 and 39.65 km have been used.

The water level starts rising in the reservoir when PMF enters into a reservoir. It is considered that all the gates of the dams are open at this moment and the reservoir is at FRL when peak of PMF enters into reservoir. Due to inadequate spillway designed capacity or due to some other reason if the inflow rate in the reservoir exceeds the outflow rate from spillway, water starts rising and over-tops the top of dam and spilling starts from earthen portion of dam which may lead to failure of dam. For dam break analysis, sometimes pipe failure of dams is also considered. In this case, the size of orifice and its location in the body of the dam is defined. The reservoir water starts oozing out from a very small circular hole and develops into a well defined opening (shape), generally assumed as trapezoidal for earthen dam. With the passage of time and under the influence of huge quantity of flow, considerable amount of dam materials is eroded away; the size of opening increases and also its base is lowered towards the bottom of the dam. Hence the three parameters namely time of breach (T), side slope of breach section (S) and size of breach (W) are very significant in defining the breach condition in any dam. The value for each parameter is governed by type of dams, construction materials etc.

In the study both Maithon and Panchet are earthen dams having length of 4.06 km and 6.4 km respectively. The breach time (T), breach width (W) and slope of breach section (S) have been assumed as 1 hr, 1 km and 1:1 for the dams.

The flood in Barakar river is considered separately and routed upto the confluence point to compute the outflow hydrograph. This outflow hydrograph is considered as lateral inflow between sections 5.8 km and 6.8 km while routing the flood in Damodar river. For simulation of dam break floods in both dams, it is assumed that the dams fail due to inflow of PMF in the reservoirs. The breach parameters are $T = 1$ hr,

Table 1: Probable Maximum Flood Hydrograph at Maithon Dam Site

Time (hr)	*Flow (Cumec)*	*Time (hr)*	*Flow (Cumec)*	*Time (hr)*	*Flow (Cumec)*	*Time (hr)*	*Flow (Cumec)*
0	100	30	4800	60	26246	90	4000
6	100	36	8500	66	24700	96	2500
12	100	42	13500	72	15000	102	2000
18	100	48	18500	78	7000	108	1000
24	1000	54	25000	84	4900	114	700

Table 2: Probable Maximum Flood Hydrograph at Panchet Dam Site

Time (hr)	*Flow (Cumec)*	*Time (hr)*	*Flow (Cumec)*	*Time (hr)*	*Flow (Cumec)*	*Time (hr)*	*Flow (Cumec)*
0	1000	24	12000	48	38875	72	6000
6	1100	30	20000	54	35000	78	4000
12	1400	36	28000	60	19750	84	2000
18	4500	42	36000	66	9900	90	1100

W = 1000 m, and S = 1:1 for both the dams. The following 4 cases failures of two dams are possible. *Case A1*—Only Panchet dam fails while PMF passes safely through the spillway of Maithon dam. *Case A2*—Only Maithon dam fails while PMF passes safely through the spillway of Panchet dam. *Case A3*—In this case both Maithon and Panchet dams fail when their PMF enters into the respective reservoirs. *Case A4*—In this case the respective PMF passes safely from the spillway of Maithon and Panchet dams without any failure of dam.

Failure of Maithon Dam

The reservoir is at FRL (152.4 m) when PMF enters the reservoir and the reservoir level starts rising even if all the gates of the spillway are open. When reservoir level increases to 156.2 m (top of dam is 156.06 m) the dam breaks. With this initial condition, the model result shows that the water level in the reservoir reaches 156.2 m after 7.9 hours since impingement of peak into reservoir and dam breaks at this moment. So the total outflow from the dam till 7.9 hours is outflow through spillway only after which the breach starts developing and total flow from dam consists of through spillway as well as through breach section. Though the reservoir level is still rising and it rises upto 156. 32 m at 8.08 to 8.18 hours, when the flow from spillway is maximum, but by this time the breach section has not been fully developed and having width of 280 m only. The breach develop to a size of 1000 m at 8.9 hours (one hour after initial formation of breach) and also the base of breach starts lowering down towards bottom of the dam. At this time the outflow from the breach section is at maximum (values from model output).

Flow in Barakar River at the Confluence

There are two types of outflow is possible in Barakar river at the confluence of two rivers due to the various failure condition of Maithon dam. The two flood hydrographs are computed by routing the dam break flood from Maithon dam up to the confluence of two rivers as shown in Table 3. Hence the following types of inflow from Barakar river is possible as shown in Table 4 below.

Table 3: Lateral Inflow from Barakar River at the Confluence of Two Rivers

Time (hr)	*Flow (cumec)*	
Cases Breach Status	*(C1) Breaches*	*(C2) Not Breaches*
0	1253	1243
60	1456	1539
12	39013	8471
18	36641	10142
24	28888	12814
30	20656	7518
36	15059	5659
42	12000	4328
48	10000	2866
54	9000	2100

Table 4: Inflow Details from Barakar for Various Failure Cases of Panchet & Maithon Dam

Failure Case	*Failure Condition of Dam*		*Flow Type*
	Panchet	*Maithon*	
A1	fails	safe	C2
A2	safe	fails	C1
A3	fails	fails	C1
A4	safe	safe	C2

Failure of Panchet Dam under PMF

It has been considered that the Panchet reservoir is at FRL (135.64 m) when the peak of the PMF enters into it. Though all the gates of dams are open the water level in the reservoir rises and reached 139.30 m, the top of the dam after which it starts overtopping. The dam fails when the water level reaches the height of 139.40 m. The model result shows that this condition develops 5.2 hours after the peak of PMF enters into the reservoir when the breach starts to form up to which the total outflow from dam is confined to spillway section only. After 5.2 hours the outflow from breached section also starts and breach develops into its complete size (1000 m) in 1 hour (time of breach) i.e after 6.2 hours when the outflow from breached section is at its maximum value of 55,143 cumec. The total volume of water discharged from the reservoir is 3,088 M cubic meter, it includes, the volume of PMF and the reservoir storage upto FRL. The outflow from the reservoir is routed in the downstream river section assuming the lateral inflow from Barakar river between section 5.8 to 6.8 km. Depending on the various combination of failures of Maithon and Panchet dam various cases like A1, A2, A3 and A4 as mentioned in Table 4 have been analyzed.

The flood hydrograph attenuates as the flood moves towards downstream from the dam site. Figures 2(a)–(d) show the flow hydrograph and corresponding stages at selected locations along the Damodar river for various cases of dam break failure. These figures also show the time of occurrence of maximum discharge and maximum stage since the entrance of peak of the inflow hydrograph into reservoirs. The maximum discharge and maximum stage reached at a particular section is shown in the figures. The profile of maximum water level attained by dam break flood at various sections along river Damodar downstream of Panchet dam is shown in Figure 3. The four curves in the figures are corresponding to 4 cases of dam break situation under PMF condition. In the figure, it is observed that in case of A2 and A3, the maximum stage after 6 km d/s of Panchet dam suddenly falls in comparison to that of for Case A1 and A3. In fact in cases of A2 and A3, Maithon dam fails and therefore the flow in the Barakar river is very high and it creates a drainage congestion condition at the confluence, about 6 km d/s of Panchet dam. This reason may be attributed to rise in maximum water level in cases of A2 and A3 upto 6 km. The time of occurrence of this maximum stage is shown in Figure 4. These two figures should be read simultaneously to know the time of occurrence of maximum stage at any cross section. It is to mention here that the time of occurrence is for the maximum stage and it should not

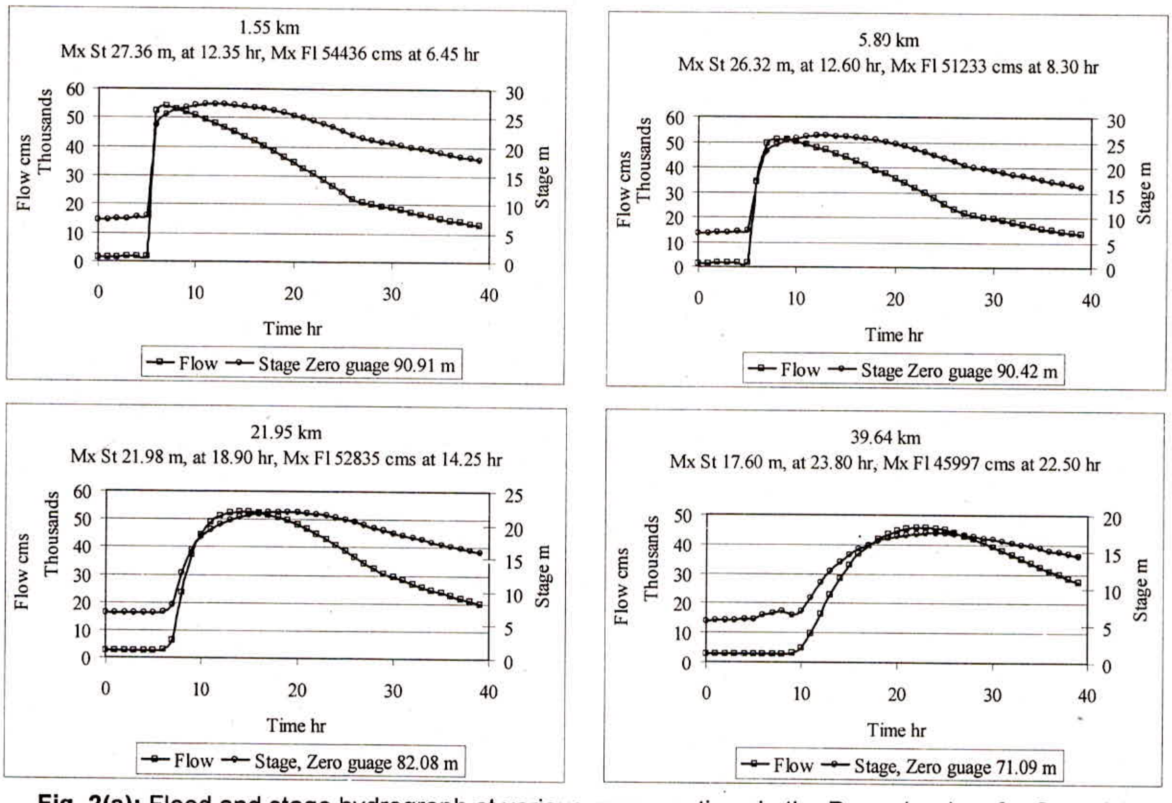

Fig. 2(a): Flood and stage hydrograph at various cross sections in the Damodar river for Case A1

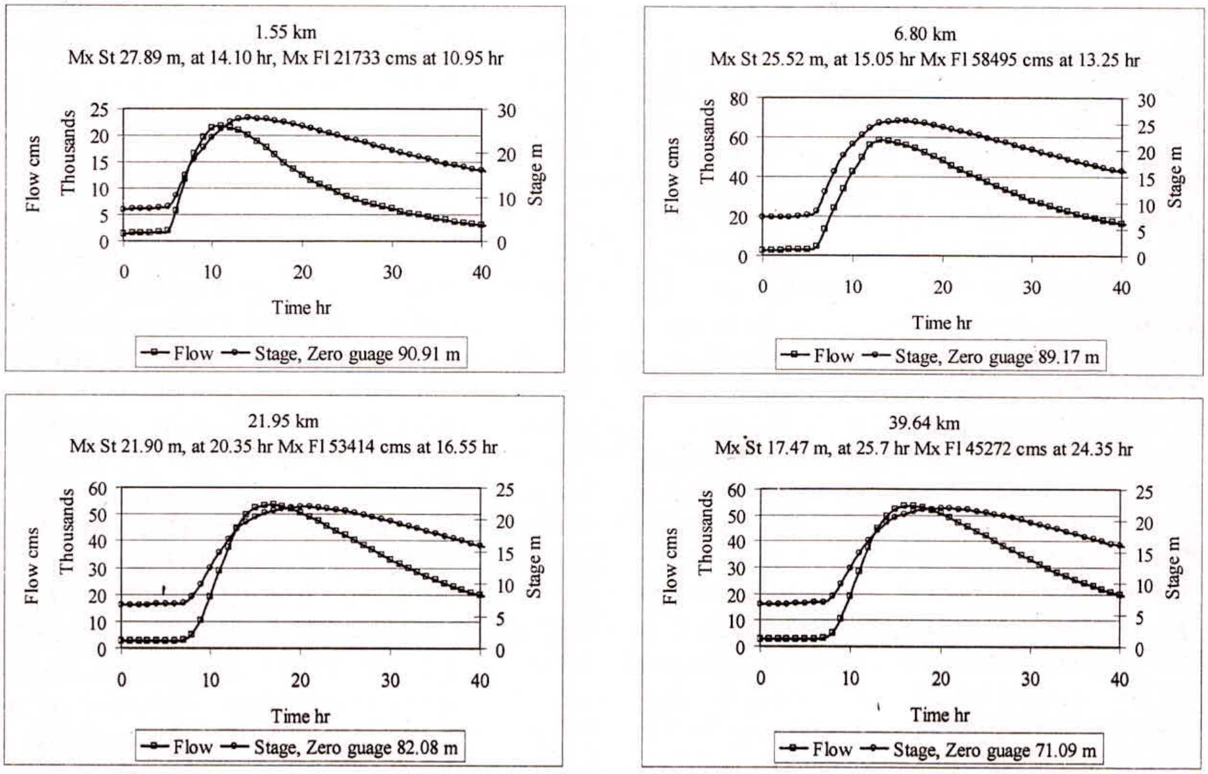

Fig. 2(b): Flood and stage hydrograph at various cross sections in the Damodar river for Case A2

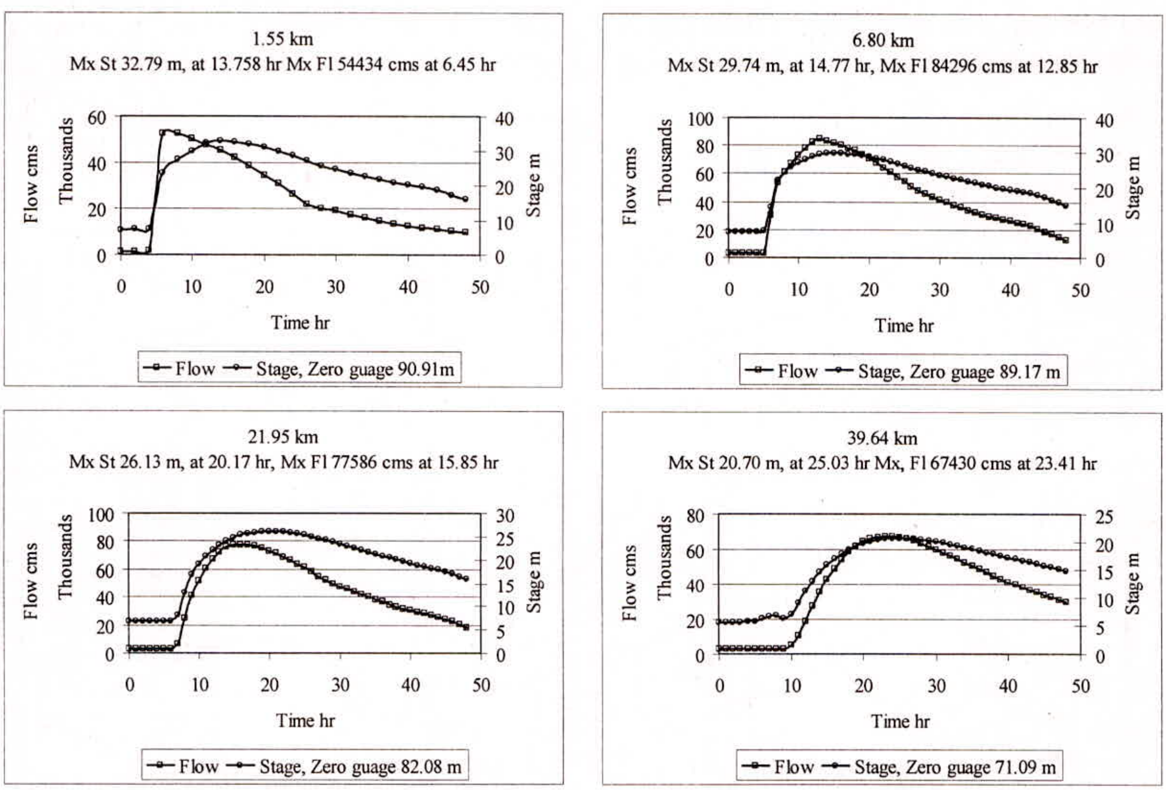

Fig. 2(c): Flood and stage hydrograph at various cross sections in the Damodar river for Case A3

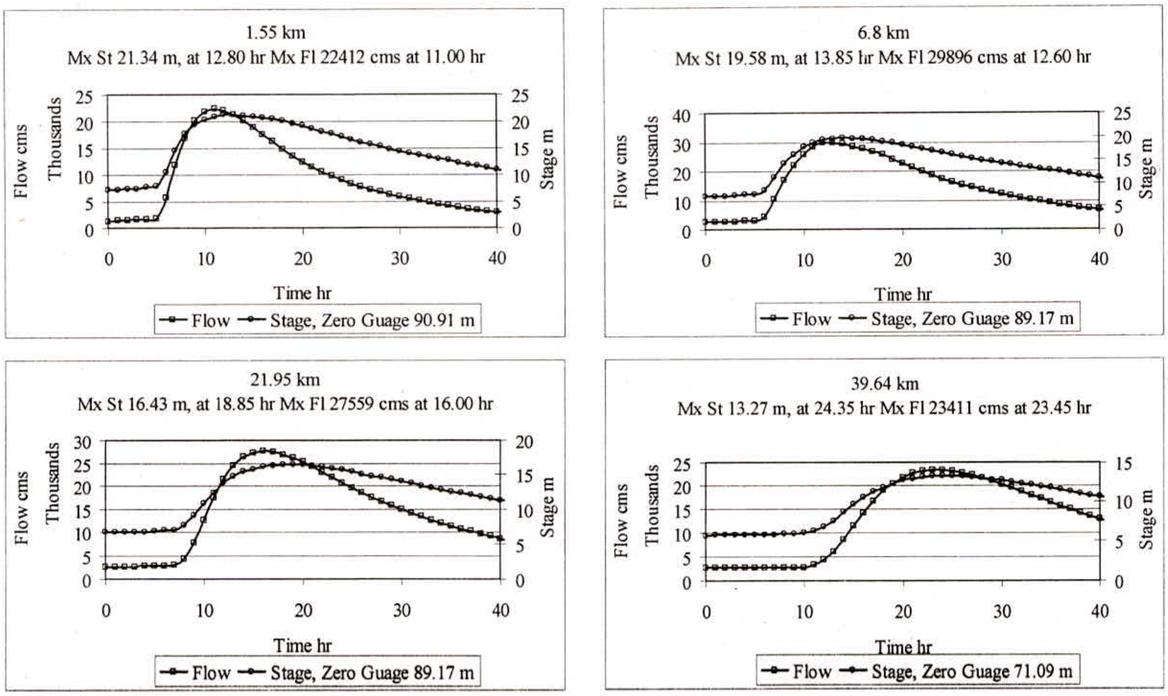

Fig. 2(d): Flood and stage hydrograph at various cross sections in the Damodar river for Case A4

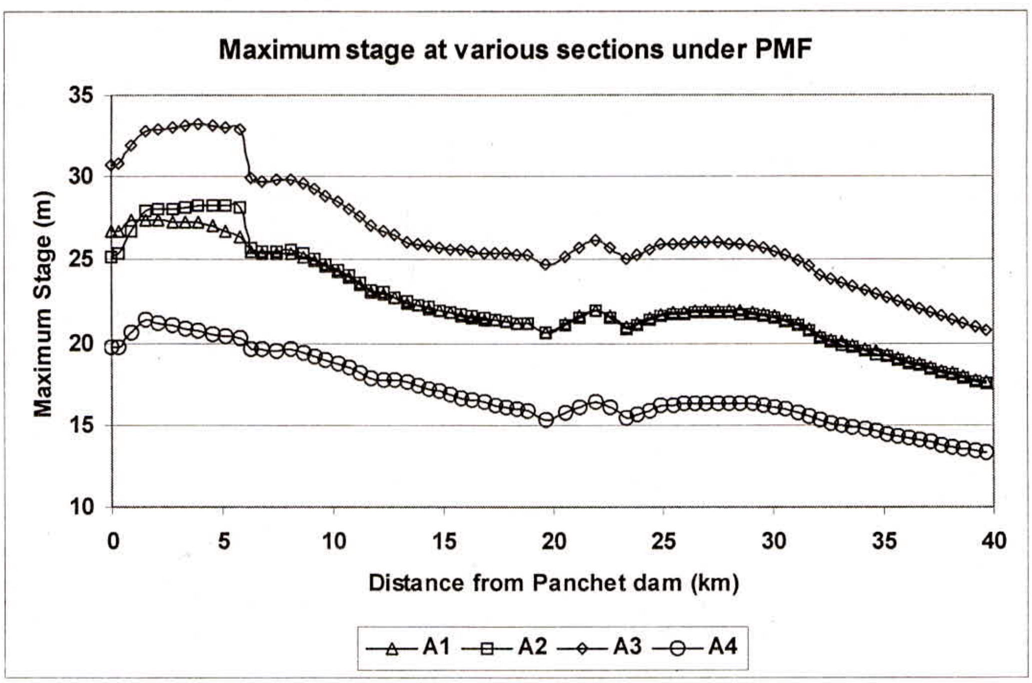

Fig. 3: Maximum stage occurred at sections along river Damodar d/s of Panchet dam

be confused with the time available for flood preparedness. In fact, the flood above the danger level might have occurred much before the occurrence of maximum stage at a given section. The inundation maps for every case are prepared by overlaying the water-surface-profile-map of a particular failure case over the digital elevation map of the area. The map shows the water depth in 8 classes and its area in hectare. This inundation map is superimposed over a base map showing the important places and communication network as shown in Figures 5(a) to 5(d). The flood inundation upto 0.50 m due to dam/s failure may be considered as moderate zone from disaster point of view and predominantly causes property losses. While the inundation above 0.50 m and upto 2 m may be considered as severe zone and induce loss of life and property both. With the inundation above 2 m, the situation is really catastrophic (catastrophic zone) and in fact very little efforts could be possible towards flood relief. It would be advisable if we restrict human settlement and commercial/institutional activities in catastrophic zone to minimize the loss. In case of existing settlements in this zone, proper warning and/or evacuation planning may be finalized for this zone. For severe zone, some high patches may be identified and developed properly to act as rehabilitation centers in the event of flooding.

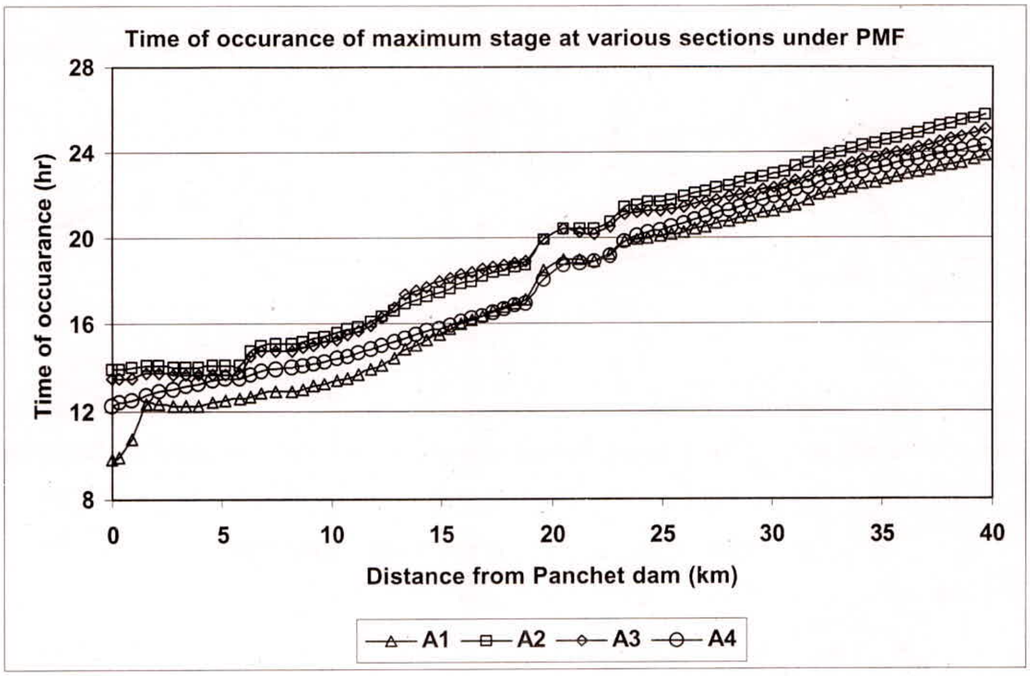

Fig. 4: Time of occarrence of maximum stage

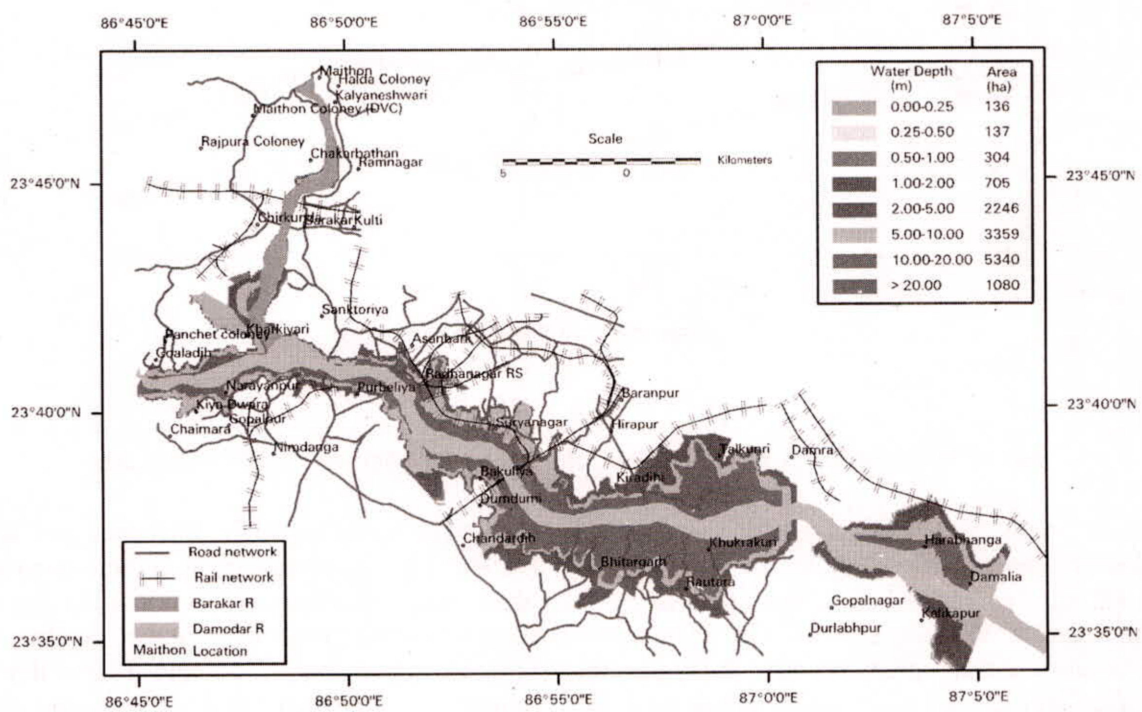

Fig. 5(a): Inundation map for case A1, (Panchet dam fails while Maithon dam remains intact)

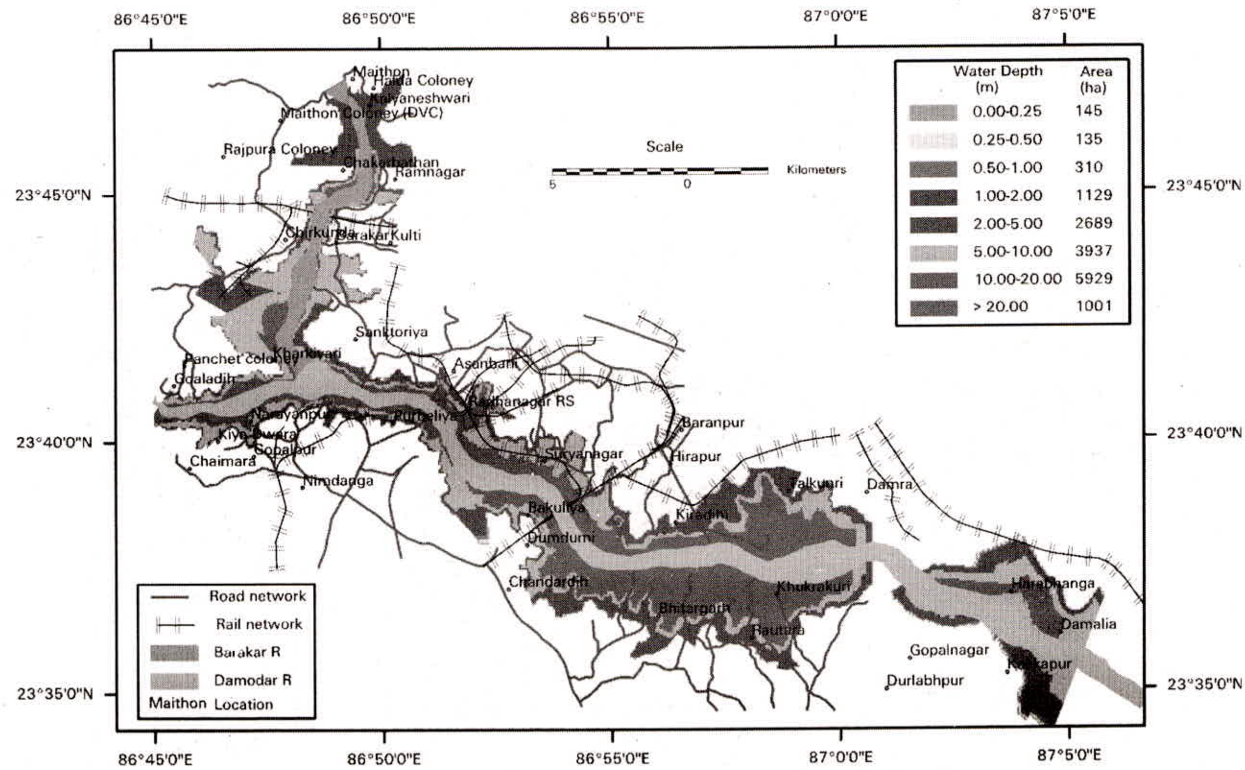

Fig. 5(b): Inundation map for case A2, (Maithon dam fails while Panchet remains intact)

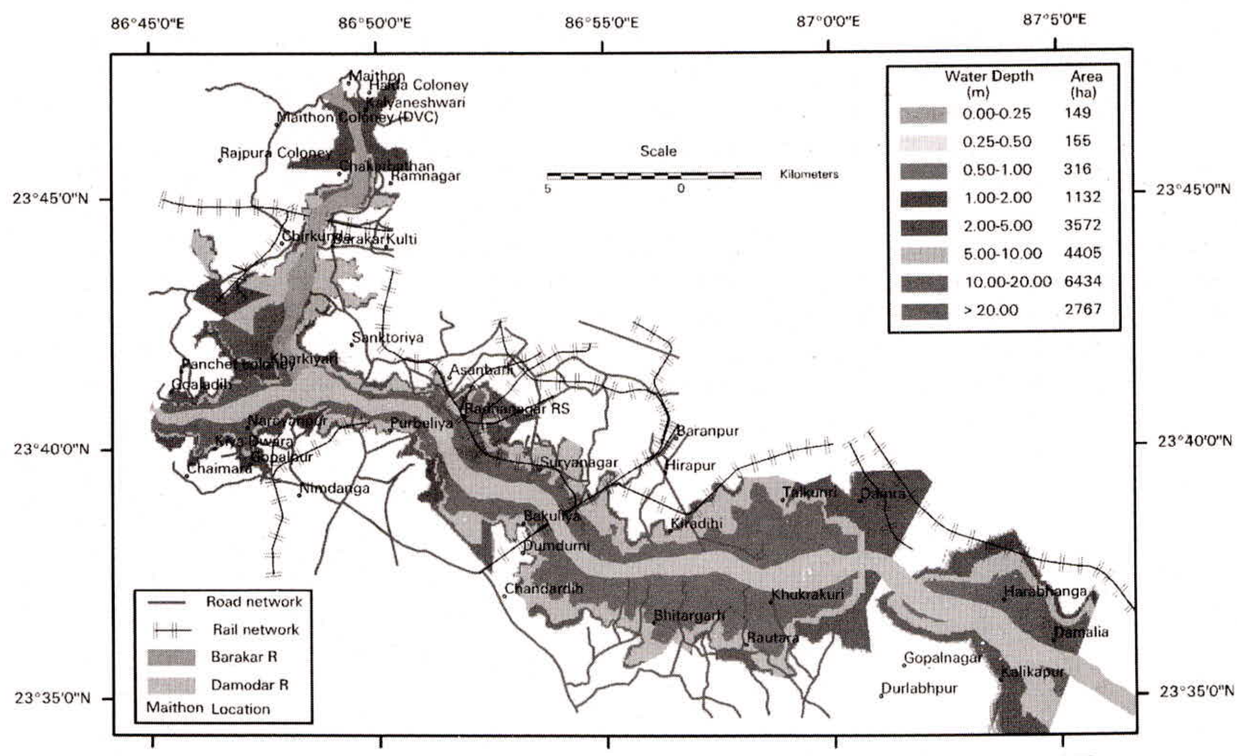

Fig. 5(c): Inundation map for case A3, (both dam fail)

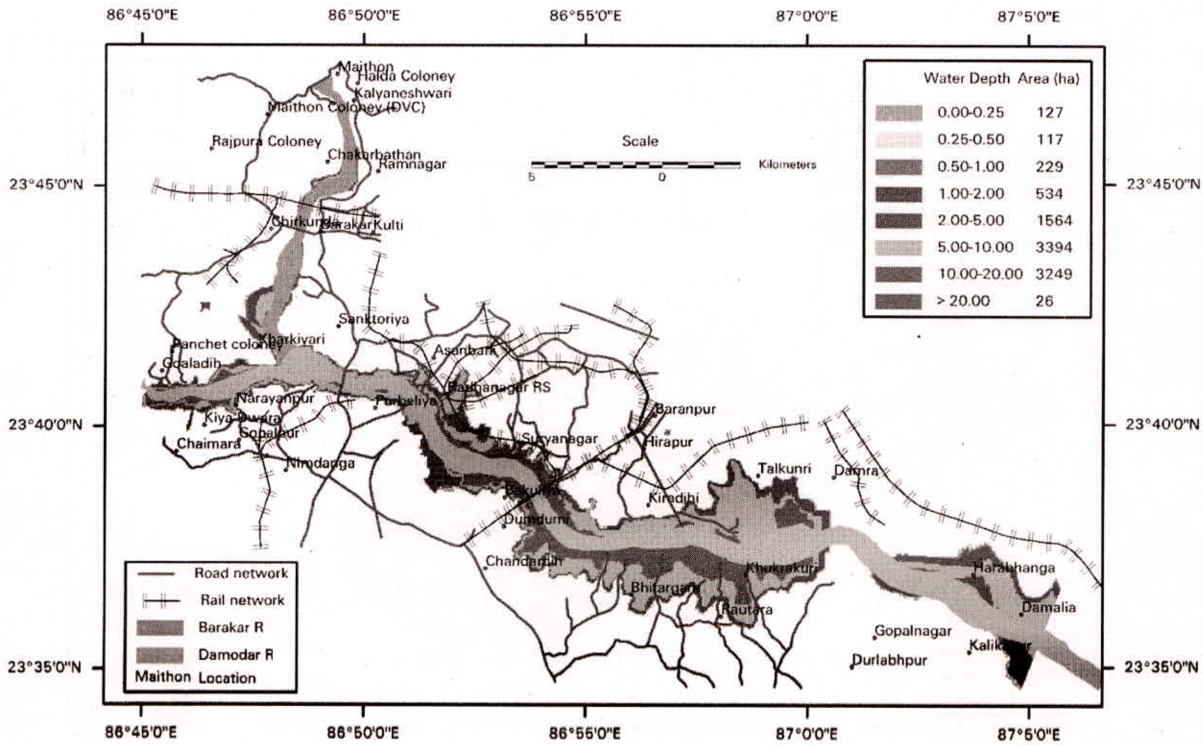

Fig. 5(d): Inundation map for case A4 (None of two dam fails)

CONCLUSIONS

The following conclusions have been drawn:

(a) NWS DAMBRK model can be applied with the limited data availability and yields useful information. In this study, the model is applied and maximum discharge, maximum stage are estimated at various river cross sections.

(b) The maximum stage reached at any section is of vital importance as it determines whether that section will be inundated or not. The inundation map provides information about the extent of inundation and also the magnitude of inundation.

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