GEOMORPHIC EFFECTIVENESS OF FLOOD ON LOWER TAPI RIVER, INDIA USING 1D HYDRODYNAMIC MODEL

P V Timbadiya[1]; P L Patel[2] and P D Porey[3]

ABSTRACT

In present study, calibration of one dimensional hydrodynamic model (MIKE 11) is presented using the geometric and hydrological data of lower Tapi river, India. The calibrated model has been used to simulate the flood of year 2006 to arrive various hydraulic quantities along the river during the flood. The estimated hydraulic quantities, in turn, are used to compute unit stream power and energy expanded during the flood to assess its impact on geomorphology of the river system.

Keywords: Channel geomorphology; unit stream power; energy expenditure; 1D hydrodynamic model; lower Tapi River.

1. INTRODUCTION

Indian rivers, in general, and the Tapi river, in particular, are vulnerable to high-magnitude floods at interval of several years to decades (Gupta, 1995; Kale, 2003; Kale, 2007). Geomorphic effects of floods depend upon magnitude, frequency, flood power, duration of effective flow and channel geometry. Channel geomorphology of Indian rivers is controlled largely by monsoon floods. It creates huge forces and likely to be geomorphically effective if persists for longer duration and power expenditure is high (Costa and O'Connor, 1995). The geomorphic effectiveness of the flood can be defined as the ability of a flood to affect the form of landscape (Wolman and Gerson, 1978). In the absence of the hydraulic modeling of the river, it is very difficult to compute the distribution of stream power per unit boundary area over the time. Calculation of unit stream power requires energy slope, which were approximated as the bed slope in previous studies (Kale and Hire, 2004; Kale, 2007). In this study, one dimensional hydrodynamic model using MIKE 11 (DHI, 2000) has been developed using geometric and hydrological data of the lower Tapi River. The developed model has been utilized to simulate the flood of year 2006 for computation of hydraulic characteristics in the river system. The simulated energy slope for flood, computed from one dimensional model, has been used to compute the unit stream power and energy expended during the said event. These computed parameters are, in turn, used to evaluate the geomorphic effectiveness of the flood and its power to initiate motion of cobbles and boulder in the river bed.

[1] Assistant Professor, Department of Civil Engineering, S.V. National Institute of Technology-Surat, Surat-395007, Gujarat, INDIA (pvtimbadiya@ced.svnit.ac.in)
[2] Professor, Department of Civil Engineering, S.V. National Institute of Technology-Surat, Surat-395007, Gujarat, INDIA (plpatel@ced.svnit.ac.in)
[3] Director, S.V. National Institute of Technology-Surat, Surat-395007, Gujarat, INDIA (pdporey@svnit.ac.in)

2. STUDY AREA

The entire Tapi basin is sub divided in three sub-basins as shown in Figure 1. The Upper Tapi basin up to Hathnur (confluence of Purna with the main Tapi, 29,430 km^2), The Middle Tapi basin from Hathnur to the Gighade gauging site (25,320 km^2) and the Lower Tapi basin from the Gidhade gauging site to the sea (10,395 km^2) (Jain et al., 2007). Historical records indicate that large floods on the Tapi have occurred in 1727, 1776, 1782, 1829, 1837, 1872, 1944, 1959, 1968,1970, 1994, 1998 and 2006 (Kale and Hire, 2004). The flood of year 1968, before construction of Ukai dam, on the Tapi River, with a peak discharge of 42500 m^{3}s^{-1} was the largest in the last century. Flood for year 2006 is highest flood, with a peak discharge of about 25780 m^{3}s^{-1}, after commencement of the Ukai dam (Timbadiya et al., 2011a).

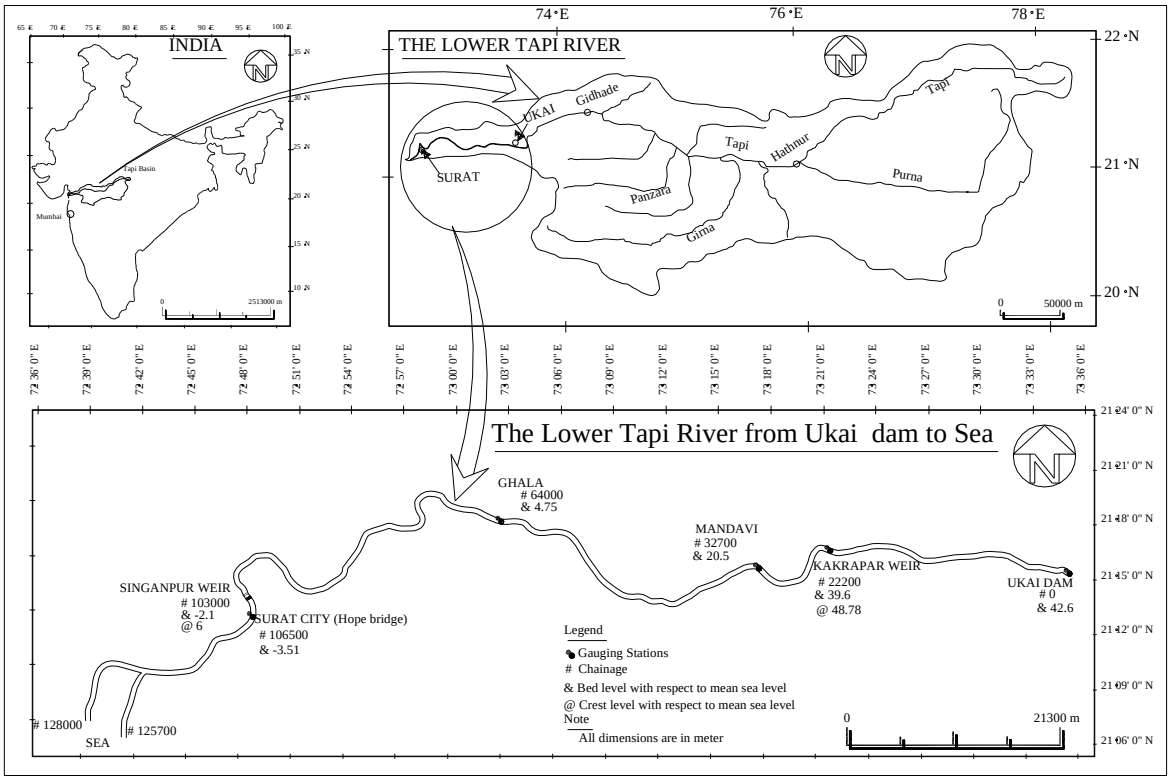

Figure 1 Map of Tapi basin including study reach in the lower Tapi River (Timbadiya et al. 2011b)

3. METHODOLOGY

The study has been carried out in three part 1) development of one dimensional model using MIKE11 and it calibration 2) Simulation of the flood of year 2006 in aforesaid developed model 3) Computation of the stream power and energy expended during the flood of year 2006.

3.1 Development of the 1D Hydrodynamic Model

The development of 1D dimensional hydrodynamic model of the lower Tapi River (as shown in Figure 1) about 128 km long, required cross sections details of the river and, accordingly, total 190 cross sections of river were used for present study. The cross sections at Ukai dam, 43m upstream of Kakrapar weir, 115m downstream of Mandavi bridge, at Ghala village, 203 m upstream of Singanpur weir and 108m downstream of Nehru bridge (Surat city) are shown in Figure 2. From the

figure, it can be seen that width of the stream (distance between left bank and right bank) increases as one move from Ukai dam to the Surat City. The model has calibrated for channel roughness using trial and error method for flood of year 1998 and it was found that a global value of Manning's roughness coefficient 'n'=0.03 had been suitable for the whole reach.

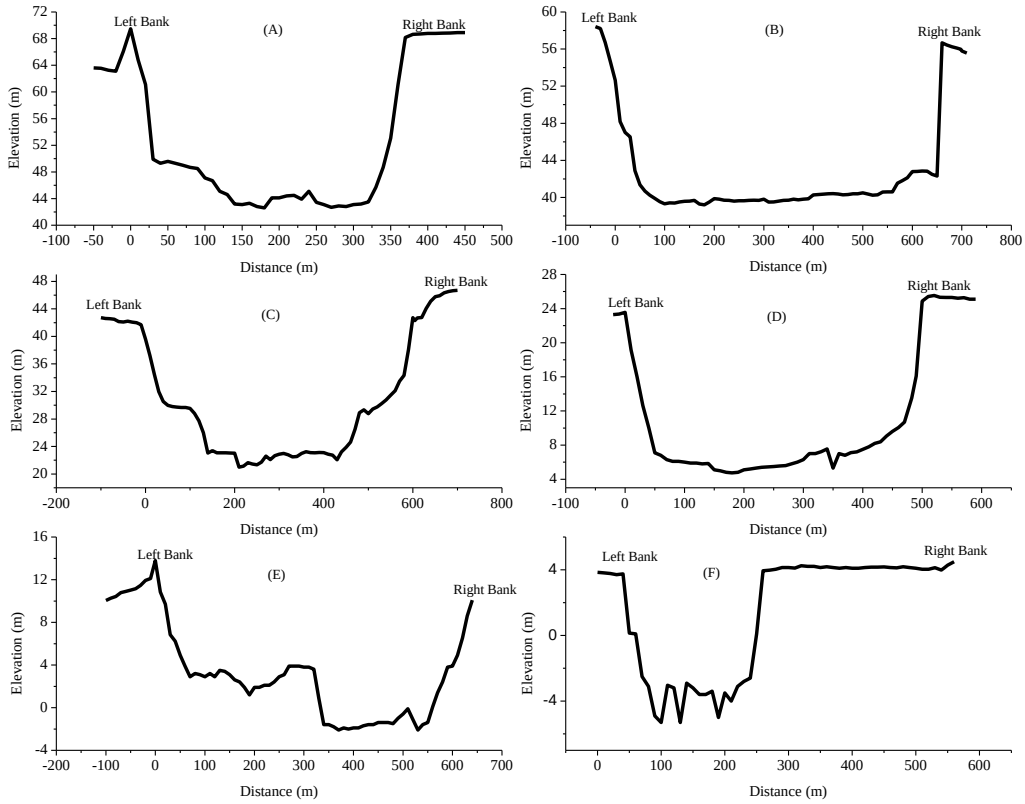

Figure 2 Cross sections of lower Tapi river at (A) Ukai dam (B) Kakrapar weir (C) Mandavi bridge (D) Ghala Village (E) Singanpur weir (F) Nehru brige (Surat City)

3.2 Simulation of the Flood of Year 2006

In order capture the flood peak, flood duration, August 6, 2006 Time: 6:00:00 to August 12, 2006 Time: 05:00:00 (total 144 hours)) has been selected as the simulation period for the flood of year 2006 by taking Ukai hourly flood hydrograph and corresponding tidal level as upstream and downstream boundary conditions respectively. Fixed time step of 5 second was selected for HD model and results were saved at frequency of 1 hour. The simulated values of different hydraulic quantities are listed in Table 1.

Table 1 Hydraulic properties of the lower Tapi River for flood of year 2006

S N	Stations	Velocity (m/s)	Froude No.	Enegy level Slope (10^{-4})	Water level Slope (10^{-4})	Bed shear stress (N/m^2)
		Max	Max	Max	Max	Max
1	Kakrapar weir	3.10	0.29	2.4	2.6	33.97
2	Mandavi bridge	3.28	0.33	2.1	9.8	50.26
3	Ghala	3.42	0.28	3.2	4.9	41.39
4	Singanpur weir	3.05	0.26	2.2	3.4	28.49
5	Surat City (Nehru bridge)	2.22	0.47	4.4	4.7	47.81

3.3 Computation of the Stream Power and Energy Expended

The effectiveness of the extreme flood in affecting the geomorphology of stream is directly related to the flood power and total energy expended during the flow. Calculation of unit stream power requires energy slope, which were approximated as the bed slope in previous studies (Kale and Hire, 2004; Kale, 2007). The simulated energy slope for flood, computed from calibrated one dimensional model, has been used to compute the unit stream power and energy expended during flood of year 2006 in the present investigation. The specific stream power can be defined as

$$\omega = \gamma QS / w \tag{1}$$

where, ω is stream power per unit boundary area in Wm^{-2}, γ is specific weight of clear water (9800 Nm^{-2}), Q is discharge in m^3s^{-1}, S is energy slope and w is the top flow width in m. The total energy expended (Ω in J/s) during the flood could be computed as area under the time series curve of stream power for flood duration i.e.,

$$\Omega = \int (\gamma QS / w) dt \tag{2}$$

where t is time in seconds.

The developed 1D model was utilized for computation of the boundary shear stress, unit stream-power and energy expended during flood at important locations (Mandavi bridge, Ghala gauging station and Nehru bridge (Surat city) gauging station) along the lower Tapi River for flood of year 2006 (magnitude 25780 m^3s^{-1}). The temporal variations in stream-power of the flood were computed and are plotted for aforesaid locations in Figures. 1, 2 and 3 respectively.

Critical unit stream power values necessary to entrain cobble and boulders were taken from Kale (2007) to evaluate geomorphic effectiveness of flood 2006 on the lower Tapi River.

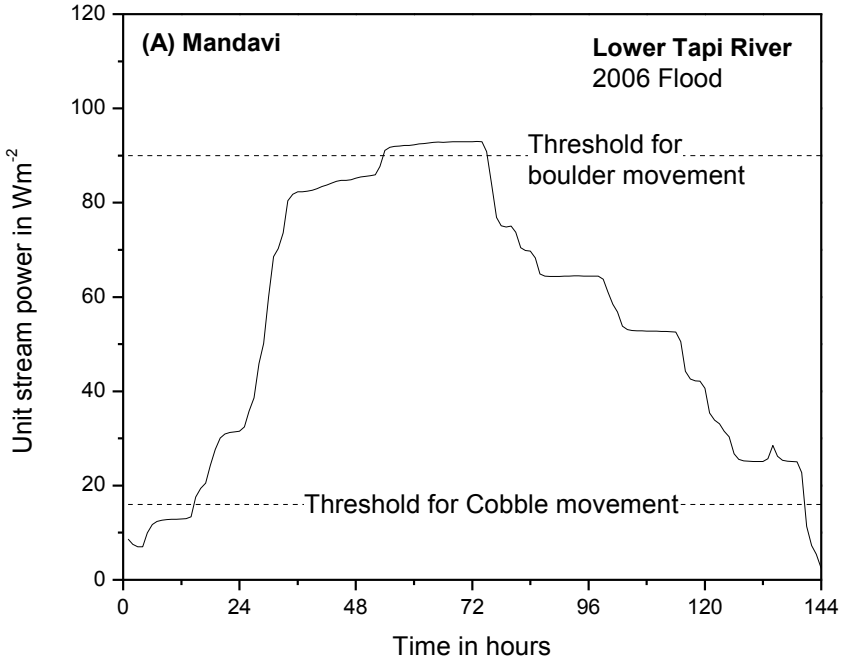

Figure 1 Time series of unit stream power for flood of year 2006 at Mandavi bridge

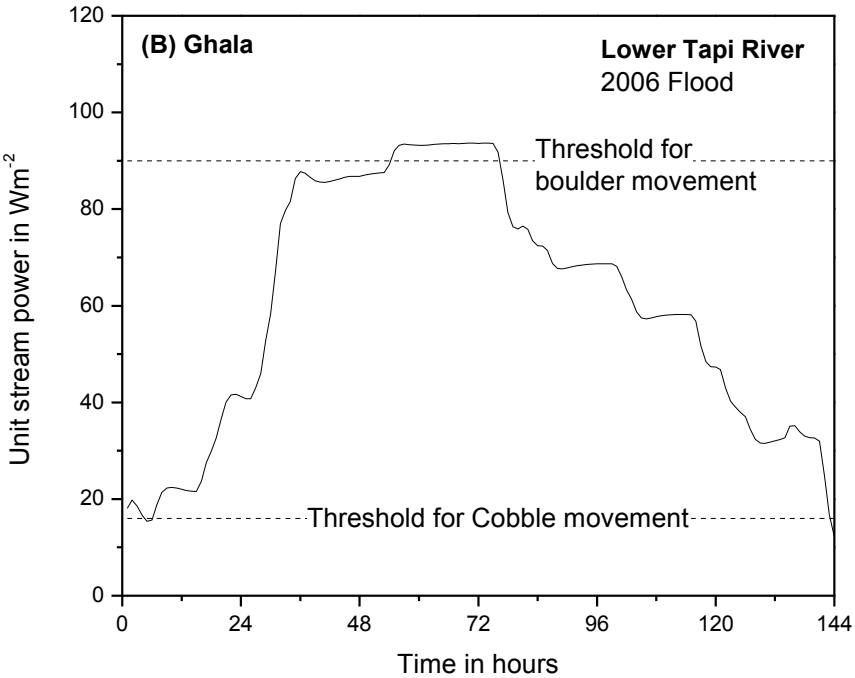

Figure 2 Time series of unit stream power for flood of year 2006 at Ghala gauging station

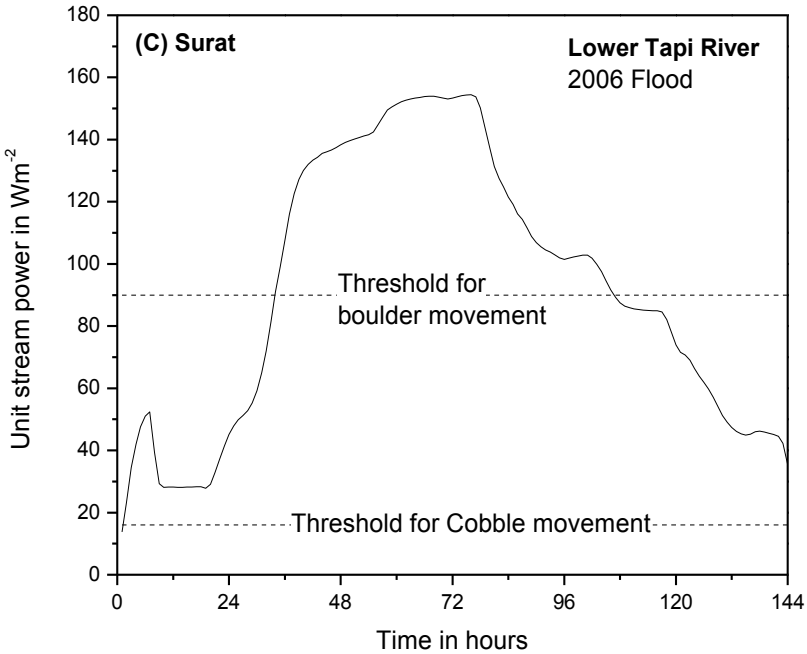

Figure 3 Time series of unit stream power for flood of year 2006 at Surat City (Nehru bridge)

The computation indicated that peak unit stream power at Mandavi, Ghala and Surat were 92.94, 93.67 and 154.45 Wm^{-2} respectively for flood of year 2006. The peak unit stream power for all the stations were sufficiently above the threshold power for cobble and boulder movement, 16 Wm^{-2}. Total energy expended during flood of year 2006 at Mandavi, Ghala and Surat have been found to be 28.7×10^6 J, 31.06×10^6 J and 47.60×10^6 J respectively. However, the peak stream power values for all stations have been found to be less than Magilligan's (1992) minimum threshold 'critical' unit stream power (300 Wm^{-2}) associated with major morphological adjustments in gentle gradient alluvial channel in humid and sub-humid regions. From foregoing study, it can be concluded that floods of magnitude to the order of 2006 flood were sufficient to initiate motion of large cobbles and boulders in the lower Tapi River, however, such floods may not cause major morphological changes in the same river system.

4. CONCLUSIONS

The geometry and hydrological data of the lower Tapi River have been used to calibrate 1D hydrodynamic model of the lower Tapi River with a global value of the Manning's roughness 'n' =0.03. The calibrated model, in turn, has been used to simulate different hydraulic quantities including energy slope along the lower Tapi River, India. The simulated energy slope and top width, in turn were used to compute the unit stream power and energy expended during the flood of year 2006. The unit stream power and energy expended during 2006 flood have been found to be 154.54 Wm^{-2} and 47.60×10^6 J respectively in the Surat City (Nehru bridge) which is less than minimum threshold of critical unit stream power associated with major morphological adjustments in the gentle gradient alluvial channel. However, the flood of year 2006 was having sufficient power to initiate the motion of boulders and cobbles available in the river bed.

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