Flood Forecasting Using One-Dimensional Numerical Model - HECRAS

Sudhanshu Dixit and Rajesh Gujar

***Abstract*— Flood causes immense damage, risk to property and loss of life. The present study addresses the simulation of flood for flood year 2006 for the lower Tapi river, Gujarat, India. The stage discharge relationship was also developed. Contour map of Tapi river was used for describing the river reach and cross-sections of the study area. Using geometric and hydrological data, the 1-D hydrodynamic model was developed using HECRAS (4.1) software. The developed model was calibrated for the 2006 flood using flood hydrograph and downstream boundary conditions. The calibrated model was validated using flood data of the year 2003 and 2006 respectively. The simulated flood levels were compared with the corresponding observed values at three stations (Weir-causeway, Sardar bridge, Magdalla bridge) provided by CWPRS, Pune. In the present study maximum water surface level were found from the aforesaid calibrated model. The results of the present study were helpful in flood forecasting and determining the critical sections required flood protection schemes along the lower Tapi river.**

***Keywords*—Flood, HECRAS, One Dimensional Modeling, Water Surface Elevation.**

I. Introduction

Every year, many parts of the country are affected by huge floods, causing immense damage, the risk of property and loss of life. The behavior of rivers has many complexities and in this respect, computer models are efficient tools in order to study and simulate the behavior of rivers with the least possible cost. Floods are recurrent phenomena in India from time immemorial. Different regions of the country have different climates and rainfall patterns. India is traversed by a large number of river systems. The rivers of north and central India are prone to frequent floods during the south-west monsoon season. Surat is one of the major important cities of Gujarat. It is a locus of trade and economic activities along with varieties of industries starting from the cotton industry, diamond industry, sugar industry to petrochemical industries located in or around the nearby area. Any natural calamity which causes loss of lives to property & infrastructure along with effects of industrial processes going on has serious impact on the economy of the state. Due to urbanization and the encroachment of the flood plain of Tapi, its flood carrying capacity was reduced. Hydrodynamic models that reproduce the hydraulic behavior of river channels have been proven to be effective tools in floodplain management (Horritt et al., 2007). In the past, many researchers developed a model for studying the behavior of rivers (Nandalal, K. D. W., (2009), Majewski, W., (2008), Pramanik et al., (2009), Vijay et al., 2007). The past records showed that large flood have occurred on the Tapi river in 1727, 1776, 1782, 1829, 1837, 1882, 1883, 1884, 1944, 1945, 1949, 1968, 1970, 1998, 2006 and 2013. In 2006, almost 80 % of the area of Surat city was flooded. It is required to do the modeling of flood in the lower Tapi river to implement structural (i.e. levee along the banks) and non-structural measures for flood control (Timbadiya et al., 2014). The past flood events must be studied and analyzed properly in order to propose adequate flood control & protection measures in time to come. In this study, effort towards simulating a flood forecasting model using HEC-RAS software is carried out. The developed model was calibrated for the 2006 flood using flood hydrograph and downstream boundary conditions. The calibrated model was validated using flood data of the year 2003 and 2006 respectively. The simulated flood levels were compared with the corresponding observed values at three stations (Weir-causeway, Sardar bridge, Magdalla bridge) provided by CWPRS, Pune. In the present study, the maximum water surface level was found from the aforesaid calibrated model which were helpful in flood forecasting and determining the required flood protection measures at various cross-sections along the river.

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II. Numerical Modeling

A. HECRAS Software

Hydrologic Engineering Centre-River Analysis System (HEC-RAS) is one-dimensional software, which is designed to perform steady flow water surface profile computations through natural rivers and full networks of natural and engineered channels, unsteady flow simulations, and movable boundary sediment transport computations. Furthermore, HEC-RAS is also capable to perform water quality analysis. A key element is that all three components will use a common geometric data representation and hydraulic computation routines (Brunner & HEC, 2010). For making calculations, HEC-RAS requires boundary conditions for each type of data. These boundary conditions are important to determine the mathematical solutions to the problems. Boundary conditions are required to obtain the solution to the set of differential equations describing the problem over the domain of interest. In HEC-RAS, there are several boundary conditions available for steady flow and sediments analysis computations. Boundary conditions can be either external specified at the ends of the network system (upstream or downstream) or internal used for connections to junctions.

B. *Model Description*

In this study, unsteady HEC-RAS model, which is based on finite difference solutions of the Saint-Venant equations (Equations (1)-(2)), has been used to simulate the flood in the lower Tapi river.

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

$$\frac{\partial Q}{\partial t}+\frac{\partial (Q^2/A)}{\partial x}+gA\frac{\partial H}{\partial x}+gA(S_0-S_f)=0 \qquad (2)$$

where A = cross-sectional area normal to the flow; Q = discharge; g = acceleration due to gravity; H = elevation of the water surface above a specified datum or stage; S_o = bed slope; S_f = energy slope; t = temporal coordinate and x = longitudinal coordinate.

III. Study Area and data collection

A. *Description of Study Reach*

The Tapi river is one of the major rivers of peninsular India with a length of around 724 kilometers (450 miles). It is one of only three rivers in peninsular India that run from east to west - the others being the Narmada River and the Mahi river The river rises in the eastern Satpura Range of southern Madhya Pradesh state, and flows westward, draining Madhya Pradesh's Nima region, Maharashtra's Kandesh and east Vidarbha regions in the northwest corner of the Deccan Plateau and south Gujarat, before emptying into the Gulf of Cambay of the Arabian Sea, in the Surat District of Gujarat. The river, along with the northern parallel Narmada river, form the boundaries between North and South India. The Western Ghats or Sahyadri range starts south of the Tapi River near the border of Gujarat and Maharashtra. The Tapi river empties into the Gulf of Khambhat near the city of Surat in Gujarat. The total drainage area of the Tapi River is 65,145 km^2, out of which 9,804 km^2, 51,504 km^2 and 3,837 km^2 lie in the Madhya Pradesh, Maharashtra and Gujarat respectively. The basin is elongated in shape, with a maximum length (i.e. 687 km) from east to west and a maximum width (210 km) from north to south. Surat city is located in the delta region of the Tapi River and has a history of frequent flooding. Maximum portion of the total rainfall arrives during the summer monsoon (i.e. June–October) season in the basin, and the flow is negligible in the rest of the year. The length of the present study reach is 12.5 km from the Causeway cum weir Singanpur to Magdalla bridge. There is no control structures located in between the study reach. Due to limitation of sediment data, the transport of sediments has not been included in the simulation of flood in the present study.

B. *Geometric and hydrologic data collection*

Numerical modeling of the Tapi river required river network, different cross-sections, hydrodynamic parameters and boundary conditions for the development of the model. A brief description of various parameters like river network, boundary conditions, calibration and validation of the model is presented in succeeding paragraph.

The geometric data for the present work was provided by the Surat Municipal Corporation (SMC) in the form of a contour map in Auto CAD (.dwg file) format and the cross-sections at several locations in the study reach were extracted from the same. The study reach has very mild slope and the effect of meandering has been neglected as there is no reasonable curvature seen in the study reach. The expansion and contraction coefficient was taken as 0.3 and 0.1 respectively. Total 77 cross-sections at various important locations on the river have been used in the model. The Flood hydrograph at Causeway cum weir Singanpur and normal depth at Magdalla bridge have been considered as up-stream and downstream boundary conditions respectively. The stage discharge data at various locations from Causeway cum weir Singanpur to Magdalla bridge was provided by Surat Irrigation Circle (SIC), Govt. of Gujarat, India. Index map of Tapi Basin and Tapi River is shown in Figure 1.

A. *Calibration and Validation of the Model*

The calibration of the model was done using the flood data of 1998 having peak discharge of 22500 cumecs. The channel roughness coefficient (i.e. Manning's n value) for the range of flows associated with the previously observed floods was selected using a trial-and-error method to obtain the best comparison between the observed and simulated flow parameters and found to be 0.025. So, n = 0.025 has been taken for further simulation of flooding. The developed, calibrated hydrodynamic model has been validated for the floods during 2006 (peak discharge flow, 25788 cumecs). The simulated river stages were compared with the observed river stages to measure the performance of the model and it is checked by root mean square error method. The flood occurring during 6 August 2006 at 8:00:00 h to 10 August 2006 at 8:00:00 h was selected as the simulation periods for the year 2006 flood, to capture the flood peak that had occurred during this interval. The cross-section of upstream and downstream stations of the study reach is shown in Figure 2.

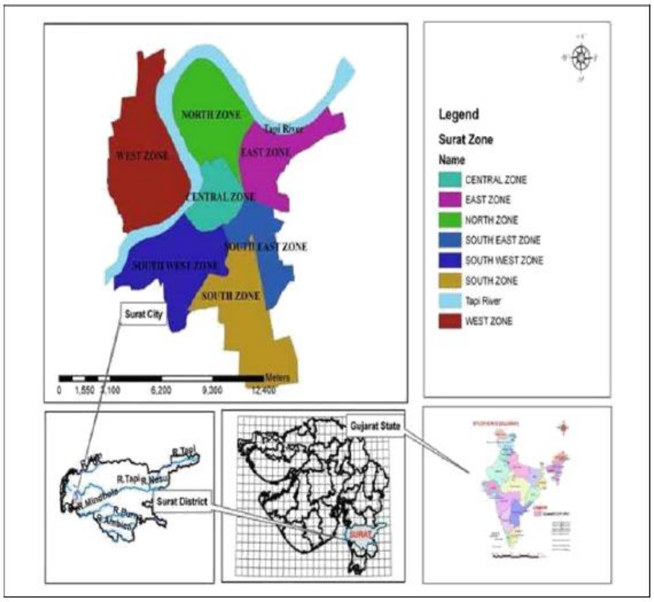
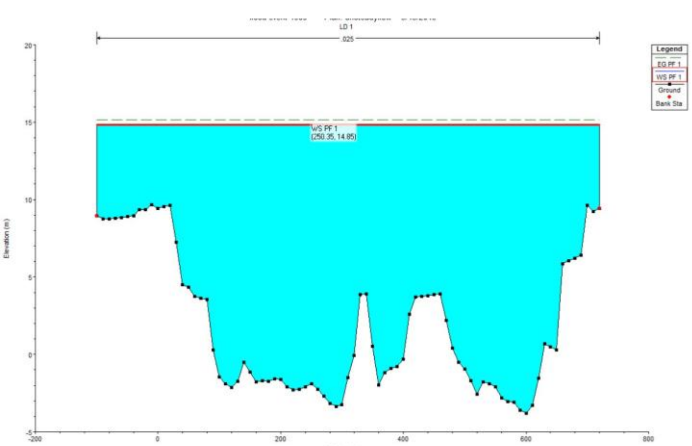


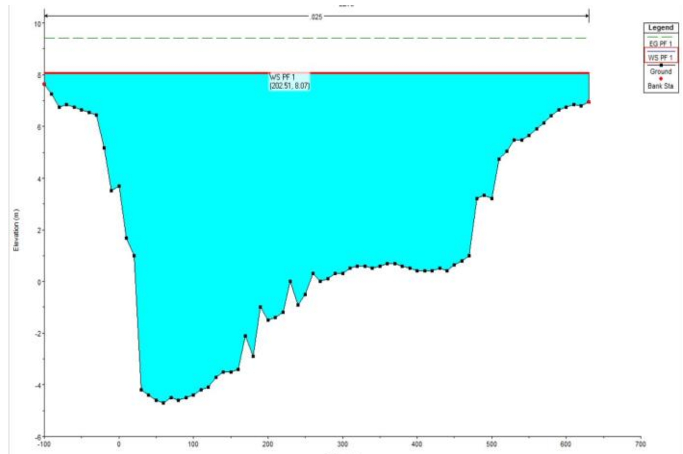
Fig. 1. Map of Tapi Basin and Tapi River.

IV. RESULT AND DISCUSSIONS

The main purpose of this study was to simulate the stages and discharges at different locations along the lower Tapi river. The simulated river stages were compared with the observed river stages to measure the performance of the model graphically and using a performance index (i.e. RMSE). The RMSE between the observed and the simulated water levels of the Causeway cum weir Singanpur (S1), Nehru Bridge (S2), Sardar bridge (S3) and Magdalla bridge (S4) stations for the year 2006 floods are shown in Table 1.



(a)



(b)

Fig. 2. Cross-sections of the lower Tapi River:
a) Causeway cum weir Singanpur; **b)** Magdalla Bridge

It is seen that the simulated results provide better performance for the gauging stations located in the lower Tapi River in the 2006 flood. In the present study, existing levees were put in the model and showed the real conditions. This developed model is helpful in proposing the river training work for flood protection in the future. From the analysis of this flood modeling, the critical section where flood control measures are required were identified. The results shows that all the four stations having existing levees were still critical sections and required flood protection work for carrying discharge as in 2006 flood or more, as shown in Figures 3-6. The stage prediction, through the simulation of flood, can be further improved using the data from several past floods in the model calibration and by studying the characteristics of the stage–discharge relationships along the Tapi river.

TABLE I: ROOT MEAN SQUARE ERROR IN THE CALIBRATION AND VALIDATION OF THE RIVER MODEL

			Stream gauging stations			
			S1	S2	S3	S4
Simulation	**Year**	**Manning's**	**Root mean square error (RMSE)**			
Calibration	1998	n = 0.015	1.001	3.729	2.557	0.911
		n = 0.020	0.301	3.209	1.847	0.911
		n = 0.025	0.859	2.639	1.107	0.911
		n = 0.030	1.239	2.039	0.377	0.911
		n = 0.035	2.019	1.449	0.323	0.911
Validation	2006		0.822	0.986	1.212	0.911

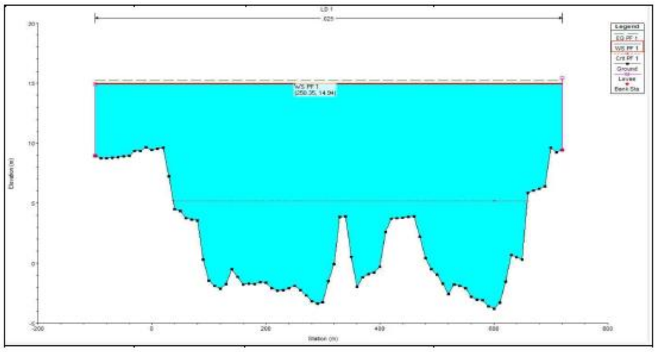


Fig. 3. River station at Causeway cum weir (W.L = 14.94 m), critical at left Bank

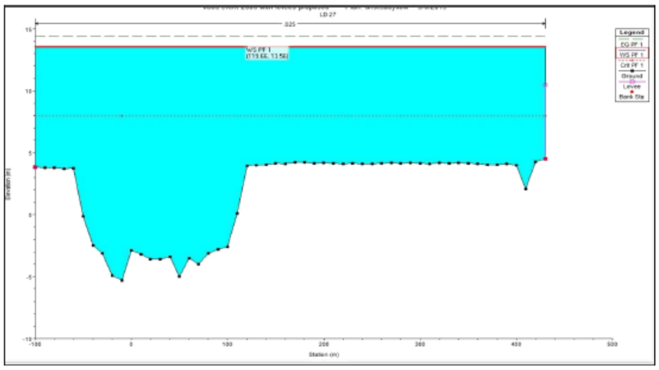


Fig. 4. River station at Nehru Bridge (W.L = 13.56 m), critical at both the banks

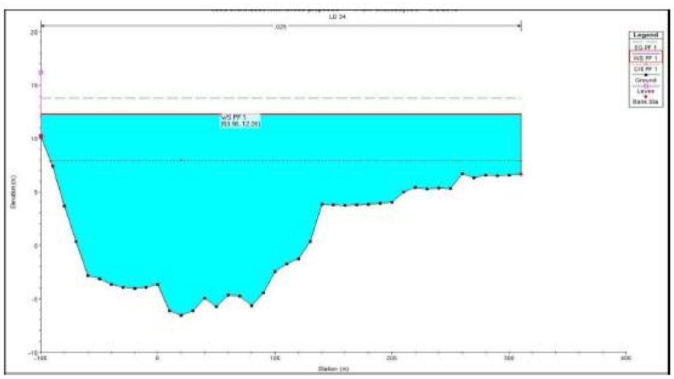


Fig. 5. River station at Sardar Bridge (W.L = 12.26 m), critical at right bank

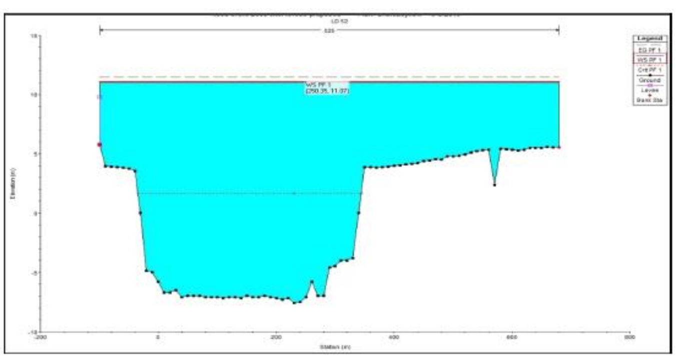


Fig. 6. River station near Magdalla Bridge (W.L = 11.07 m), critical at both the banks

V. CONCLUSIONS

In the present work, the simulation of the floods during 2006 was performed using the 1-D HECRAS model, and the results were validated for the different gauging stations along the lower Tapi river. From the present study, the following conclusions can be made:

(a) The complete one- dimensional model of the study reach was developed using the HECRAS model.
(b) The resistance coefficient was calibrated for the study reach for the flood in 1998, which was used for further flood simulations.
(c) The calibrated one- dimensional model was used to simulate the flood during 2006.
(d) The simulated water levels from model of the lower Tapi river are higher than the observed flood levels for the year 2006.
(e) The simulation results based on the numerical modeling can be more accurate, by using a two-dimensional model approach in the lower Tapi River.
(f) The stage prediction using model, through the simulation of flood, can be further improved by consideration sediment transport in the river during a flood.

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