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Comparison of Flood Routing Models (Case Study: Maroon River, Iran)

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Abstract: This study is undertaken to compare some different flood routing models including wave models and numerical models in the real field. The results of the wave models included kinematic, diffusive and dynamic wave have already been compared using laboratory data. Lack of the data field and technical support has been causes of not be investigated in the real field. In this present paper, several numerical solutions for basic equations has been developed by using Visual Basic and computer codes have been provided for them. To verify applicability of developed models in the field, Maroon River observed data including hydrologic, hydraulic and geometric data's have been gathering from Khuzestan Sources of Water Management (SWM), Iran. The develop software in this research program has been run for the selected river. In the next step, to find out the accuracy models, outputs have been comparing together. Finally, it is showing that the method of characteristics is more accurate than other models and it's calculation accuracy is acceptable.

Key words: Maroon River · Propagation · Conceptual Based Models · Numerical Based Models · Characteristics Method

INTRODUCTION

Flood is still one of the most important natural hazards threatening societies around the world and causes significant amount of damages [1]. Accurate estimation of this natural phenomenon and its propagation along river system can save thousands of people and a large amount of investment [2]. In general, flood is unsteady, its mathematical description is nonlinear and there is no analytical solutions for numerous river engineering problems that can be conveniently investigate by means of mathematical models [3]. Mathematical models must properly describe the physical processes and provide a numerical solution to a system of differential equations that solved together with suitable boundary conditions and empirical relationships that describe resistance to flow and turbulence [3]. The differential equations describing river mechanical problems are usually simplified forms of the equations conservation of mass and momentum, leading to a set of partial differential equations involving two independent variables (time and space or two spatial variables) [4]. Once a river engineering problem have been defined and a mathematical model chosen, field data need to be gathered to describe initial and boundary conditions, geometrical similitude, materials properties and design condition. Additional data are also required for calibration and verification [5]. Model calibration is usually necessary to find values of parameters such as Manning's roughness coefficient [1]. Model verification involves simulation for a different set of data field with the coefficients previously obtained in the calibration [1]. Previous investigators have dealt with comparing different schemes limited two or three models. Sivaloganathan compares two schemes of the method of characteristics [6]; Maghsoudi used the method of lines solution along the method of characteristics (MOLAC) to improve accuracy and stability of the method of characteristics (MOC) [7]. Subsequently, Maghsoudi and Simon compared MOLAC results with the same results obtained using lax-wendroff explicit finite difference scheme and have shown that the MOLAC is more stable and accurate [8]. Kabir and Orsborn used an implicit method to predict flood wave propagation and comparison its results with laboratory data from physical model [9]. They showed that the implicit method of solution could predict the depth hydrograph successfully. Musavi-jahromi and Sivakumar studied flood propagation

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in open channel by numerical methods; they considered three numerical methods of solution for unsteady flow equations namely the explicit, implicit and the method of characteristics using laboratory data [10]. Singh reviewed some recent advances of flood routing [11]. Research shows still flood and its corresponding investigation is important to engineers [12-15]. This paper deals with explicit, implicit and the method of characteristics as numerical methods and kinematic and diffusive wave as wave models. The original computer codes have been providing for numerical and conceptual models. Data field from Maroon River has been gathering and various models have been running for selected river system. Finally, numerical models have been comparing and the most accurate one is introduce. Besides, conceptual models also were comparing and amongst the more accurate one are introduce.

MATERIAL AND METHODS

Experimental Data: Maroon river basin which is selected as model field to compare. The hydrometric stations data of Behbahan and Chamnezam, obtained from sources of water management (SWM) of Khuzestan province, Iran. Figure 1 shows river reach between Chamnezam hydrometric station (49°55' 4″East and 30°44' 51″ North) and Behbahan hydrometric station (50°20' 30″East and 30°41' 03″ North).

Table 1: Distance of each available cross section from upstream boundary, Behbahan

Node No.	Distance from Behbahan (Km)	Distance from prior node (Km)
1	3.015	3.015
2	4.888	1.873
3	7.837	2.949
4	9.191	1.354
5	10.750	1.559
6	12.254	1.504
7	14.053	1.799
8	20.757	6.704
9	28.744	7.987
10	34.008	5.264
11	40.238	6.226
12	44.054	3.816

Hydrographs of Behbahan station for various return periods are presented in Figure 2. This station is the upstream boundary for each selected model.

The average bed slope is 0.0052 and 12 cross-sections have been available, their distances from upstream boundary are given in Table 1.

Total length of the reach between Behbahan and Chamnezam hydrometric stations is 44. 054km. Figure 3 shows the observed hydrographs (Return period = five years) for Behbahan and Chamnezam stations. As shown the figure, peak flow equal 2000 m^3/s is observed in Behbahan station and peak flow equal 750 m^3/s is shown for Chamnezam station.

Fig. 1: Maroon River basin located between Behbahan and Chamnezam stations

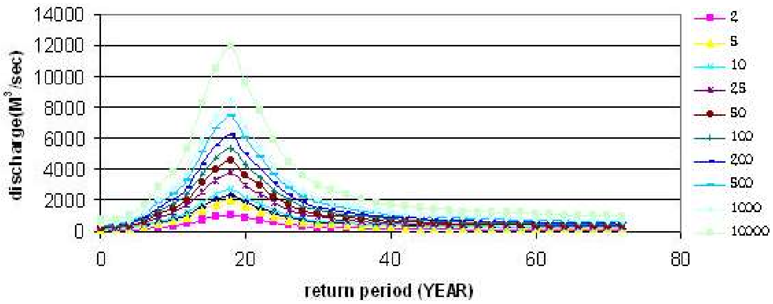

Fig. 2: Flood hydrographs for various return periods, Behbahan Station

Each model needs rating curve of the downstream boundary to be run. Figure 4 presents the rating curve of Chamnezam hydrometric station. Corresponding equation that has been found out from regression analysis is $Q=2.347y^{2.1324}$

Basic Equations: De Saint-Venant undertook the earliest study on the unsteady flow in open channel in 1871. The mathematical models presently available to treat gradually varied, unsteady flow problems generally can be divided in two categories: (1) numerical models, which solve the St. Venant equations for gradually varied, unsteady flow and (2) wave models that solve various approximations of the St. Venant equations. A system of partial differential equations for the movement of 1D flood flow along longitudinal direction may be written as:

$$\frac{\partial Q}{\partial t}+\frac{\partial A}{\partial t}=0 \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\left(\beta\frac{Q^2}{A}\right)}{\partial x}+g^A\left(\frac{\partial y}{\partial x}-S_0+S_f\right)-q\beta V_x=0 \tag{2}$$

Where:
Q = Flow discharge
x = Longitudinal coordinate
A = The cross section area
S_0 = Slope of channel bed in longitudinal coordinate
S_f = Friction slope
g = Acceleration of gravity

Wave Models (Kinematic Wave Model): In this method relinquished from pressure and acceleration terms of momentum equation and slope of energy line is equal to beds slope, (S_0-S_f) then Equation 2 can be written as [16]:

$$S_0=S_f \tag{3}$$

Solution of Equation 1 and 3 gives Equation 4 as follow:

$$\frac{\partial Q}{\partial x}+\alpha\beta Q^{B-1}\frac{\partial Q}{\partial t}=0 \tag{4}$$

$$Q_{i+1}^{j+1}=\frac{\frac{\Delta t}{\Delta x}Q_i^{i+1}+\alpha\beta Q_{i+1}^{j}\left(\frac{Q_{i+1}^{j}+Q_i^{j+1}}{2}\right)^{\beta-1}}{\frac{\Delta t}{\Delta x}+\alpha\beta\left(\frac{Q_{i+1}^{j}+Q_i^{j+1}}{2}\right)^{\beta-1}} \tag{5}$$

α and β are constant coefficient and their values are:

$$a=\left[\frac{np^{\frac{2}{3}}}{\sqrt{S_0}}\right] \; and \; \beta=0.6 \tag{6}$$

Kinematics wave method does not need downstream boundary condition. This model is applicable to river basin with steep slope.

Diffusive Wave Model: Two first terms in the left hand side of Equation 2 assumed negligible. The following equation is obtained as the dynamic equation for the diffusive model.

$$S_f=S_0-\frac{\partial y}{\partial x} \tag{7}$$

Equations 1 and 7 can be resulted in the following equation.

$$\frac{\partial Q}{\partial t}+C\frac{\partial Q}{\partial x}=M\frac{\partial^2 Q}{\partial x^2} \tag{8}$$

In Equation 8 M and C are changed with progress in time of flood. They could be calculated as much as is progressed using Equation 9.

$$M = \frac{Q}{2BS_0} \quad and \; C = \frac{5}{3}\frac{R^{\frac{2}{3}}}{n} S^{\frac{1}{2}} \tag{9}$$

Final model of diffusive wave scheme is:

$$Q_i^{i+1} = \left(1 = \frac{\Delta t}{\Delta x} C_i^j - 2M_i^j \frac{\Delta t}{\Delta x^2}\right) Q_i^j + \left(C_i^j \frac{\Delta t}{\Delta x} + M_i^j \frac{\Delta t}{\Delta x^2}\right) Q_{i-1}^j + M_i^j \frac{\Delta t}{\Delta x} Q_{i-1}^j \tag{10}$$

Numerical Based Models

Explicit Model: Lax-Wendroff explicit scheme is selected for this section. In order to solve Equation 1 and 2 this scheme gives Equation 11 corresponding to Equation 1.

$$A_i^{j+1} = A_i^j - \frac{\Delta t}{\Delta x}(Q_{i+1}^j - Q_i^j) \tag{11}$$

Lax-Wendroff scheme final equation is as follow:

$$Q_i^{i+1} = \bar{Q}_i^j - \frac{\Delta t}{\Delta x}\left(\frac{Q_2^2}{A_2} - \frac{Q_1^2}{A_1}\right) - gA_3 \frac{\Delta t}{\Delta x}(y_2 - y_1) + g\Delta t A_3 (S_0 - S_{fa})$$

In which, A_1, y_1 and A_2, y_2 are time average of cross section area and depth at (i-1)th and (i) th nodes respectively. A_3 is average of A_1 and A_2. Q_1 is the average discharge of flow at (i-1)th and (i)th nodes for the last time level. Q_2 is the average discharge of flow at (i)th and (i+1)th nodes for the last time level. $\bar{Q}_i^j$ Is the average discharge of flow at (i-1)th, (i)th and (i+1)th nodes for the last time level.

Implicit Model: Equation (1) And (2) can be solved implicitly using the Lax-Wendroff scheme. Then leads to Equation (11) and (12) as below:

$$Q_1 = \frac{Q_{i-1}^j + Q_{i-1}^{j+1} + Q_{i+1}^j + Q_i^{j+1}}{4} \tag{13}$$

$$Q_2 = \frac{Q_i^j + Q_i^{j+1} + Q_{i+1}^j + Q_{i+1}^{j+1}}{4} \tag{14}$$

Characteristics Model: The generalized unsteady flow equations shown in Equation (1) And (2) can be transformed by the method of characteristics and by applying the appropriate linear interpolation to calculate velocity and celerity of flow as:

$$V_i^{j+1} = \frac{V_A^J + V_B^J + 2V_B^J + g(2S_0 - S_{fA}^J - S_{fB}^J)}{2} \tag{15}$$

$$C_i^{j+1} = \frac{V_A^J + 2V_B^J + V_B^J + 2C_B^J + g(S_{fB}^J - S_{fA}^J)\Delta t}{4}$$

Where A, B are nodes in left and right hand side of the nodal point that its hydraulic characteristic should be calculated. The hydraulic properties of A and B can be obtained using the linear interpolation technique. The depth of flow is calculated from the celerity of flow.

RESULTS AND DISCUSSION

Results: The results of five models are shown in Figures 5, 6, 7, 8 and 9. These hydrographs show the flow discharge versus time at 12 cross sections in Maroon River, These figures show that hydrograph that entered in the upstream boundary is decreased continually at downstream stations.

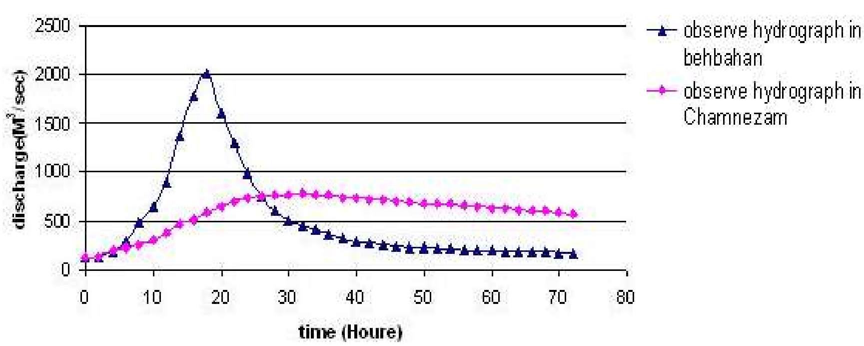

Fig. 3: Observed flood hydrographs at Behbahan and Chamnezam stations (Return period =5 years)

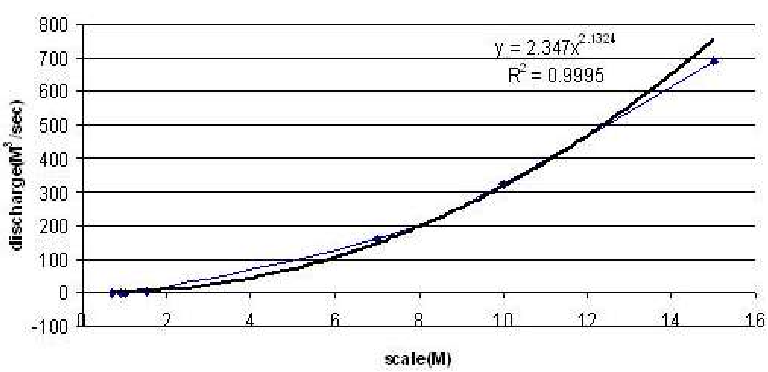

Fig. 4: Rating curve of Chamnezam hydrometric station

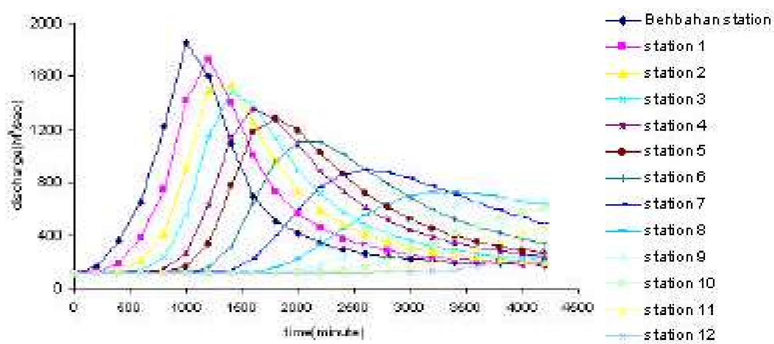

Fig. 5: Kinematics wave model predicted hydrographs along the selected reach

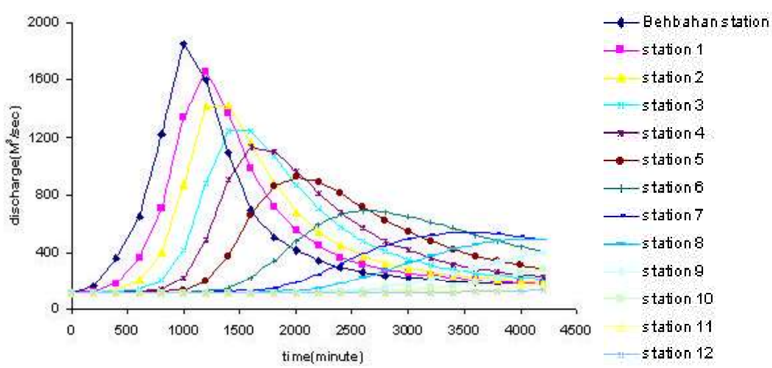

Fig. 6: Diffusive wave model predicted hydrographs along the selected reach

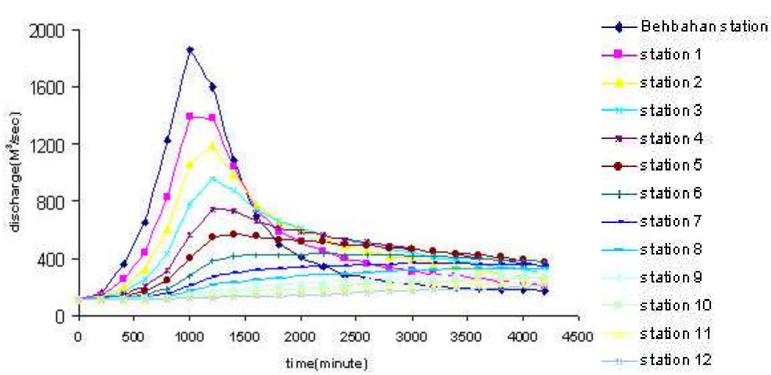

Fig. 7: Explicit model predicted hydrographs along the selected reach

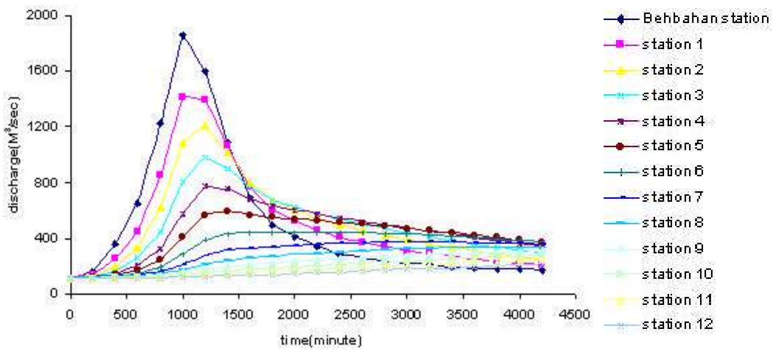

Fig. 8: Implicit model predicted hydrographs along the selected reach

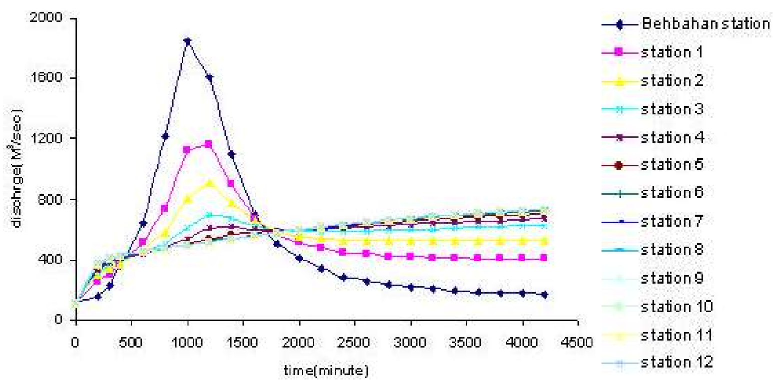

Fig. 9: Characteristics model predicted hydrographs along the selected reach

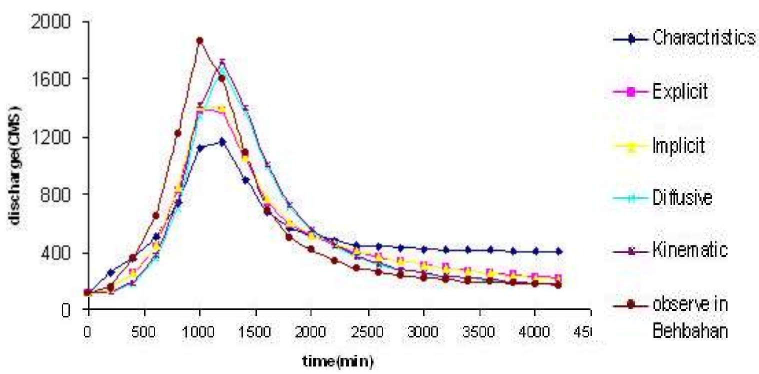

Fig. 10: predicted hydrographs for five methods in node 1

DISCUSSION

Figure 10 shows the predict hydrograph of five models in one station immediately after Behbahan hydrometric station. This figure show that the models such as kinematic wave and diffusive wave which neglect some terms in the momentum equation, they have greater discharge pick point, because whit relinquished some terms the forces resistance are more reduced. But in the method of characteristics that have full terms of momentum and dynamically solved has a lower hydrograph and from first to fifth nodes is located in foot of the mountain zone and have a steep slope this causes that the methods of kinematics and diffusive give a better answer. Table 2 is showed the predict picks of hydrographs behind the outlet hydrograph that measured in Chamnezam hydrometer station. This table shows that the hydrograph of kinematics, diffusive, explicit and implicit schemes are affected by distance. But the method of characteristics has good prediction; this shape of characteristics hydrograph is to assume to solve the general equation.

Table 2: Peak of predicted hydrographs, Chamnezam station

Method	Peak flow (m3/Sec)
Kinematics Wave	261.5
Diffusive Wave	128.8
Explicit	209.4
Implicit	213.6
Characteristics	733.5
Observed	775

Observed hydrograph in the last node at a distance of 44km from the upstream boundary indicates that the predicted hydrograph by the method of characteristics matches very closely with recorded discharge. However, the deviation between measured and predicted by another method remains high; this shows that the method of characteristics is more accurate than other selected methods in the real field.

CONCLUSION

The unsteady flow was simulated using five model and original computer codes were provided for all methods. The kinematic and diffusive wave as wave models, the explicit, implicit and the method of characteristics as numerical models were selected. Developed models were run for field data in Maroon River, Iran. Results from various models were compared and it is shown that overall, characteristic model can simulate real field very successfully. It has been able to predict the peak of hydrographs very close to observed data.

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REFERENCES

1. French, R.H., 1986. Open Channel flow, McGraw Hill.
2. Mahmood, K. and V. Yevjevich, 1975. Unsteady flow in open channel. Vol. 1, Water Resources Publication, Fort Collins, Colorado.
3. Mujumdar, P.P., 2001. Flood wave propagation the Saint-Venant equations, Department of Civil Engineering, Indian Institute of Science.
4. Simon, D.B., 1992. Future trends and needs in hydraulics. J. Hydr. Engrg, 118(12): 1608-1620.
5. Stokstill, R.L., 2000. Hydraulic modeling of trapezoidal high-velocity channels, US Army Crops of Engineers, ERDC/CHL HETN-11-2
6. Sivaloganathan, K., 1978. Flood routing by characteristics methods. J. Hydr. Engrg, ASCE, 104(HY7): 1075-1091.
7. Maghsoudi, N., 1990. The method of lines solution of unsteady open channel flow equations along characteristics. Proc. 1990 National Conf. on Hydraulic Engineering. Cheng and Hill (eds.), 1: 415-420.
8. Maghsoudi N. and Simon D. B., 1991. On the application of artificial viscousity in computational hydraulics. Proc. 1991 National Conf. on Hydraulic Engineering, edited by R. M. Shame. pp. 966-971
9. Kabir, N. and J.F. Osborn, 1986. Laboratory model studies of flood wave propagation. US Army Corps of Engineers. Water Forum 86: 1951-1958.
10. Musavi-jahromi, S.H. and M. Sivakumar, 1994. Flood propagation in open channel by numerical methods. Water Down Under' 94. Adelaide, Australia, pp: 595-600.
11. Singh, V.P., 2004. Flow routing in open channel: some recent advance, Department of Civil and Environmental Engineering Louisiana State University Baton Rouge, LA, pp: 70803-6405.
12. Chagas, P. and R. Souza, 2005a. development of a numerical model, with explicit solution, to study flood wave propagation, Department Environmental and Hydraulics Engineering, Federal University of Ceara.
13. Chagas, P. and R. Souza, 2005b. Solution of Saint Venant equation to study flood, in rivers throgh numerical methods. Hydrology days 2005, Department of nvironmental and Hydraulics Engineering, Federal University of Ceara.
14. Fenton, J.D, 2002. The application of numerical methods and mathematics to hydrography, proc. 11th Australasian hydrographic conference Sydney, 3-6 July, Department of Civil and Environmental Engineering University of Melbourne.
15. Garcia Navarro, P., J. Burguete and R. Aliod, 2003. Numerical simulation of runoff over dry beds, university of Zaragoza Spain.
16. Jain, S., 2004. Open channel flow.