Dynamic Flood wave Routing By finite difference method

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Abstract— Flood routing is essential to control flood flow at the flood control station such that it is within the specified limit. It is a mathematical procedure used to predict the discharge and water depth due to flooding on or more points on river segment. In this paper finite difference scheme is considered for solving the channel routing problem. The main objective is to develop a computational model for flood wave routing by use of finite difference method and to validate the developed model by the observed data of Sabarmati River. Calibration of model is done. Essentially non-oscillating scheme is used for this purpose.

Key words: Flood Routing, Finite difference method, ENO scheme.

I. INTRODUCTION

Flood routing is a mathematical method used to predict changes in the magnitude and celerity of a flood wave when it propagates down rivers or through reservoirs. The peak flow and the overall shape of the flood wave change throughout its movement downstream (Fread and Linsley, cited by Tewolde, 2005). In the American Society of Civil Engineers' manual, "Nomenclature for Hydraulics," flood routing is variously defined as follows:

Routing (hydraulics) :- (1) the derivation of an outflow hydrograph of a stream from known values of upstream inflow. The procedure utilizes wave velocity and the storage equation; sometimes both. (2) Computing the flood at a downstream point from the flood inflow at an upstream point, and taking channel storage into account.

Routing flood: - The process of determining progressively the timing and shape of a flood wave at successive points along a river.

Routing stream flow:-The procedure used to derive a downstream hydrograph from an upstream hydrograph, or tributary hydrographs, and from considerations of local inflow by solving the storage equation. The purpose of flood routing in most engineering work is to learn what stages or rates of flow occur, without actually measuring them, at specific locations in streams or structures during passages of floods. The stages or rates are used in evaluating or designing a water control structure or project. Differences in stages or rates from routings made with and without the structure or project in place show its effects on the flood flows. In evaluations, the differences are translated into monetary terms to show benefits on an easily comparable basis; in design, the differences are used directly in developing or modifying the structure or project characteristics.

II. FLOOD ROUTING

A. Classification of Flood Routing

1) Reservoir routing: In reservoir routing storage is function of outflow.
2) Channel Routing: In channel routing storage is function of inflow and outflow. There are two methods in channel routing.

1) Hydrologic Method

Hydrological methods for channel routing use the principle of continuity equation to solve the mass balance of inflow, outflow and the volume of storage. These methods of routing require a storage-stage-discharge-relation to determine the outflow for each time step (Guo, 2006: Pg 437). Hydrological methods involve numerical techniques that introduce translation or attenuation to an inflow hydrograph (A review Of Muskingum-cunge, cascading reservoir. & full dynamic solution, 2008).

The continuity equation is presented below as:

$$\frac{dS}{dt} = I_{(t)} - O_{(t)}$$

Where, S is the storage between the upstream and downstream sections in m3.

T is the time in s, I (t) is the inflow at upstream section and O (t) is the outflow at downstream section in (m3/s).

Over the finite interval of time between t and t+ t, the above equation can be written in finite difference form as:

$$\frac{S_2 - S_1}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2}$$

Where the subscripts 1 and 2 refer to the values of the variables at times t and t+ t respectively (Chin, 2000).

2) Hydraulic Routing

Hydraulic flow routing procedures are becoming popular for the purposes of flood routing. This is because hydraulic methods allow flow computation to be varied in both time and space (Tung, 2002).

III. IMPORTANCE OF CHANNEL ROUTING

Channel Routing is a mathematical method to predict the changing magnitude, speed and shape of a flood wave as it propagates through waterways such as canals, river. The flood wave can emanate from precipitation runoff, reservoir releases and tides. Channel routing has long been of vital concern to man as he has sought to predict the characteristic features of flood wave in his efforts to improve the transport of water through man- made or natural waterways and to determine necessary actions to protect life and property from the effects of flooding. Commencing with investigations as early as the seventeenth century, mathematical techniques to predict wave propagation have continually been developed. With the contribution of saint Venant in 1871, the basic theory for one dimensional analysis of flood wave propagation was formulated; however, due to the mathematical complexity of saint-Venant theoretical equations, simplifications were necessary to obtain feasible solutions for the salient characteristics of the wave. Thereafter, a profusion of simplified flood routing methods appeared in the literature. It is only within the last 25 years, with the advent of high speed electronic computers, that the complete saint- Venant equations could be solved with varying degrees of feasibility.

IV. METHODOLOGY AND TOOLS

A. Methodology

There are several possibilities for approximating the partial derivatives. The spatial partial derivatives replaced in terms of the variables at the known time level are referred to as the explicit finite difference. Explicit finite difference models advance the solution of the saint-Venant equations point by point along one time line in the x-t solution domain until all the unknowns associated with that time line have been evaluated. Then, the solution is advanced to next time line. In an explicit scheme the spatial derivative and non-derivative terms are evaluated on the time line where the values of all variables are known. Only the time derivatives contain unknowns.

Thus, in an explicit model, two linear algebraic equations are generated from the two saint Venant equations at each net point. Since the two equations can be solved directly for the unknown, the equations are defined as explicit.

Essentially non-oscillating scheme is used for this purpose.

B. Tools

FORTRAN is used for programming part. Programming algorithm is shown in fig 1.

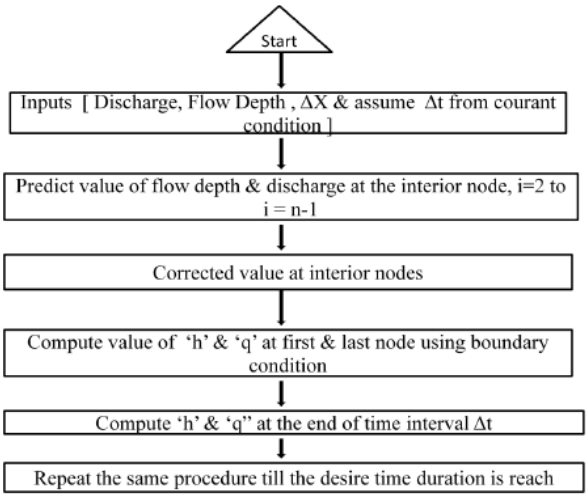

Fig. 1: Programming algorithm

C. Overview of ENO

Essentially non-oscillatory explicit finite difference scheme is second order accurate in both space and time. This scheme is simple to implement and does not require inversion of large matrices. It is a two level predictor-corrector scheme and it is also easy to incorporate general empirical equations for flow resistance and sediment transport in it. The Mathematical formulation of these equations can be written as:

$$\frac{\partial E}{\partial t}+\frac{\partial F}{\partial x}=H \qquad (1)$$

Where E, F, and H are the vectors can be defined as

$$E=\begin{bmatrix} h \\ q \\ z \end{bmatrix} \quad F=\begin{bmatrix} q \\ \dfrac{q^2}{h}+\dfrac{1}{2}gh^2+ghz \\ \dfrac{B}{P(1-\lambda)}\left(\dfrac{\partial q_{Bc}}{\partial x}+\dfrac{\partial q_{sc}}{\partial x}\right) \end{bmatrix}$$

$$H=\begin{bmatrix} \dfrac{P}{B}\dfrac{\partial z}{\partial t} \\ ghS_f \\ \dfrac{B}{P(1-\lambda)}\dfrac{\partial (C_{av}h)}{\partial t} \end{bmatrix}$$

D. Predictor approach

The predicted value of vector E at the unknown time interval is determined as follows:

$$E_k^{\ *}=E_k^{\ j}-\frac{\Delta t}{\Delta x}\left[F_{k+1/2}^{j}-F_{k-1/2}^{j}\right]+\Delta t H_k^{\ j} \quad (2)$$

In which the subscript j is the value at the known time level t and subscript * denotes the predicted value at the unknown time level, here is computational time step in y-direction and is computational spatial step in x-direction. Equation (2) must be discretized component wise for vector E to find the predicted values of h, q and z at the time level at any node k.

E. Corrector approach

The corrected value of vector E at the unknown time level j+1 at the node k, i.e. Is computed by using the predicted values

$$E_k^{\ **}=E_k^{\ *}-\frac{\Delta t}{\Delta x}\left[F_{k+1/2}^{*}-F_{k-1/2}^{*}\right]+\Delta t H_k^{\ *} \quad (3)$$

As per Alcrudo et al. (1992) and are determined from and, (which are needed to compute) using the same and which are already computed in the predictor step. This procedure gives better numerical stability.

$$E_R^{\ *}=E_{k+1}^{*}-0.5\delta E_{k+1} \qquad (4)$$

$$E_L^{\ *}=E_k^{\ *}+0.5\delta E_k \qquad (5)$$

F. Final values

Finally the values of unknown at time level j+1 i.e. at the end of time interval are given as

$$E_k^{\ j+1} = \frac{1}{2}\left(E_k^{\ j} + E_k^{\ **}\right) \qquad (6)$$

By using present algorithm, the value of h, q and z at new time level j+1 are determined at every interior node (k = 2 …….N-1). The value of these variables at the boundary nodes i.e. node 1 and N are determined using appropriate boundary conditions. The procedure to be followed for inclusion of boundary conditions and initial conditions into the finite difference scheme is problem specific (Bhallamudi and Chaudhary, 1991).

V. CONCLUSION

ENO scheme for channel routing has provided significant result. The methodology used in this study allows us to validate the model.

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