Numerical Analysis of Flood modeling of upper Citarum River under Extreme Flood Condition

R I Siregar\textsuperscript{1, 2}

\textsuperscript{1}Civil Engineering Department, Faculty of Engineering, Universitas Sumatera Utara, Jl. Dr. Mansur Kampus USU, Padang Bulan, Medan 20155, Indonesia
\textsuperscript{2}Sustainable Energy and Biomaterial Centre of Excellence, Universitas Sumatera Utara, Jl. Almamater Kampus USU, Padang Bulan, Medan 20155, Indonesia

E-mail: rizawaloed@yahoo.com

Abstract. This paper focuses on how to approach the numerical method and computation to analyse flood parameters. Water level and flood discharge are the flood parameters solved by numerical methods approach. Numerical method performed on this paper for unsteady flow conditions have strengths and weaknesses, among others easily applied to the following cases in which the boundary irregular flow. The study area is in upper Citarum Watershed, Bandung, West Java. This paper uses computation approach with Force2 programming and HEC-RAS to solve the flow problem in upper Citarum River, to investigate and forecast extreme flood condition. Numerical analysis based on extreme flood events that have occurred in the upper Citarum watershed. The result of water level parameter modeling and extreme flood discharge compared with measurement data to analyse validation. The inundation area about flood that happened in 2010 is about 75.26 square kilometres. Comparing two-method show that the FEM analysis with Force2 programs has the best approach to validation data with Nash Index is 0.84 and HEC-RAS that is 0.76 for water level. For discharge data Nash Index obtained the result analysis use Force2 is 0.80 and with use HEC-RAS is 0.79.

1. Introduction

Numerical analysis is as a technique to solve the problems in the field of engineering, which formulated in the form of mathematical equations. Mathematical equation in other conditions cannot solve by analytically but numerically. It has analytic approaches errors with value must be less than the provisions [1]. Flow pattern recognition using the physical modeling and numerical simulation helps designers to propose optimal shape for hydraulics structures. Optimal shape of hydraulic structure causes increasing their performance [2]. Need to be versed in all the formulas and theories related to the problem, analytical procedures and problems of scale and ignoring some parameters, physical and laboratory methods [3]. The model adopts two well-established empirical formulas to determine the flooding under extreme flood condition [4].

Flood events caused by the extreme flood conditions can have damaging consequences on buildings and infrastructure located in prone areas [5]. Flood simulation models can provide practitioners of flood disaster management with sophisticated estimates of floods. Despite the advantages that flood simulation modeling may provide, experiences have proven that these models are of limited use. Until now, this problem investigated by evaluations, which information demanded by decision-makers versus what models can actually offer [6].
Factors that affect flooding due to river floods when extreme flood conditions affected is river morphology. The amount of morphological change, erosion, and deposition related to peak flow conditions at the sites. The measured changes in bank full capacity were highly correlated with most hydraulic variables [7]. The aims of this study are to perform a numerical approach and modeling floods especially during extreme flooding condition. This study analyzed extreme flood condition in upper Citarum River used numerical analysis of flood modeling. This study used computation approach with Force2 programming and HEC-RAS, to investigate and model extreme flood condition.

2. Study Area and Materials

2.1. Characteristics of the River in Study Area
The upper Citarum watershed has upper Citarum River as a main river. The watershed consists of thirteen tributaries, where they form a sub-watershed. Upper Citarum River originated from well Cisanti, located at the foot of Mount Wayang, about 60 kilometers south of Bandung. Upper Citarum River has 37 kilometers in length and it flows through the southern of Bandung Regency up to Saguling Reservoir. The Figure 1 shows upper Citarum River in upper Citarum Watershed that lies in Citarum Watershed, West Java, Indonesia. The location map of river image shows at the top right of the figure 1.

![upper Citarum River](image)

**Figure 1.** The location map of Citarum Watershed in West Java that shows the location of upper Citarum Watershed as a study area

2.2. Data Sources
The data required in this study comes from the Major River Basin Organization of Citarum, Public Work Ministry. These data include upper Citarum river flow discharge in years 2001 to 2012, daily rainfall data in years 2001 to 2012, and land cover data in years 2001 and 2010. In addition, river morphology such cross section and long section of upper Citarum River data and watershed characteristic are also required for modeling. Flood modeling also requires DEMs data for 2D modeling for extreme flood that occurs in upper Citarum River. The input parameter for analysis involved rainfall intensity, land cover, river cross and long sections, characteristics of watershed, and flood extreme discharge. All of these data run in Force2 programming and HEC-RAS to get information about what happened about the influences of this flood. As validation, we use discharge data and water level from AWLR data from the Major River Basin Organization of Citarum.
3. Methods

The stages of methodology involved two programs. They are Force2 and HEC-RAS. The numerical analysis that we have done base on momentum and continuity equation, run in Force2, this program help to iterate the discharge and water level in simulation time. The result of from that program will compare to the HEC-RAS value. In this study, HEC-RAS as a comparison to know extending of this model, because in numerical analysis only as one dimensional modeling, but in HEC-RAS analysis use two dimensional modeling.

3.1. Governing Equations

Finite Element Method is the most widely used method to solve the problem of flow because its formulation is relatively easy and efficient as well as giving satisfactory results. The properties of the conservative discretization increment used to control volume approach [8]. Subsequent analysis is to determine the elevation of the base and the water level of each section, determine the cross-sectional area $A$ and a discharge $Q$ using explicit discretization Lax-Wendroff [9]. Discretization shapes that given by Lax-Wendroff to solve the equations, which is in the form of conservative equation.

\[
\frac{\partial W}{\partial t} + \frac{\partial F(W)}{\partial x} + T(W) = 0 \tag{1}
\]

\[
W_{j}^{n+1} = W_{j}^{n} + \Delta t \left( \frac{\partial W}{\partial t} \right)_{j}^{n} + \frac{\Delta t^2}{2!} \left( \frac{\partial^2 W}{\partial t^2} \right)_{j}^{n} + \frac{\Delta t^3}{3!} \left( \frac{\partial^3 W}{\partial t^3} \right)_{j}^{n} + \ldots \tag{2}
\]

\[
\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{3}
\]

\[
\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \rho \frac{Q^2}{A} + gI \right) + gAS_0 + g \frac{Q |Q|}{AC^2 R} = 0 \tag{4}
\]

3.2. Flood Modeling Method

This study performs numerical analysis with Finite Element Method. Numerical simulations derived out by the unstructured grid, Finite Element Method [11]. In the analysis phase, it will discretize the discharge equation and water level based on the fluid momentum and continuity equations. The equation solved with the help of computer programming that is Force2.

This method applied the Hydrologic Engineering Center River Analysis System (HEC-RAS) model to estimate the potential vulnerabilities of flood for different peak outflow scenarios with conclusions and recommendations [12]. All raster datasets used to create 1D and 2D HEC-RAS model. HEC-RAS is the most commonly used flood model tool in Indonesia. The HEC-RAS parameters kept unchanged for different DEMs because the goal is to investigate the sensitivity of inundation maps to topographic errors instead of trying to create new calibrated model for each topographic dataset [13].

The numerical results compared with a fully 2D model as well as with measurements in some gauge points giving satisfactory results. The simulation of a real flooding scenario in the upper Citarum River near the urban area then performed. A lateral coupling configuration provided, in which the flood wave propagation in the main channel simulated by means of a 1D model and the inundation of the riverside simulated by means of a 2D model [14]. Based on the results of numerical analysis and simulation results in HEC-RAS will be compared the results of flow discharge and water level to see the relationship between the two parameters in terms of flood modeling.

Base on discharge data in years 2001 to 2012, shows that the trend of increasing flow occurs in 2010. For further simulation, we use the flow in year 2010 as the most extreme flood events in upper Citarum River.
3.3. Flow Validation Method
In this study, the model use Nash–Sutcliffe efficiency (NI) for flow validation method. The result of comparison then determined the strength in predicting the modeling by Nash-Sutcliffe model of efficiency coefficient (E). The Nash–Sutcliffe efficiency (NI) is the two criteria most widely used for calibration and evaluation of hydrological models with observed data [15]. Nash–Sutcliffe Index can range from $-\infty$ to 1. The value of 1 (NI=1) corresponds to a perfect match of modeled discharge to the observed data. The value NI = 0 indicates that the model predictions are as accurate as the mean of the observed data, if it is less than 0; it occurs when the observed is better prediction than the model.

4. Results and Discussions

4.1. Flow Simulation Equations
Based on the result of a decrease in the continuity equation and momentum, with incorporates discretization scheme results Lax-Wendroff, the equation set forth in Taylor series as follows:

$$ W_j^{n+1} = W_j^n - \Delta t \left( \frac{\partial P}{\partial x} + T \right) + \frac{\Delta t^2}{2} \frac{\partial}{\partial x} \left[ R \left( \frac{\partial P}{\partial x} + T \right) \right] - \frac{\Delta t^3}{6} \frac{\partial^2 F}{\partial x^2} \left[ (f_{j+1}^n - f_{j-1}^n) + (2\Delta x)T_j^n \right] + \frac{1}{2} \frac{\Delta t^2}{\Delta x^2} \left[ \left( R_{j+1}^n - R_j^n + \frac{\Delta x}{2} (T_{j+1}^n + T_j^n) \right) - R_{j-1}^n \left[ f_j^n - f_{j-1}^n + \frac{\Delta x}{2} (T_j^n + T_{j-1}^n) \right] \right] - \frac{\Delta t}{6} \left( T_j^n - T_{j-1}^n \right) \right) (5) $$

Definitely, $W_j^{n+1}$ and $W_j^n$ consists of cross sectional area A and discharge Q. The equation above can derive into the equation to determine the value of A and Q. The equation becomes Lax-Wendroff scheme that derived into the equation in the programming language. From these two equations then determined the parameters of other channels. The following is equation upstream and downstream boundary conditions.

$$ \frac{Q_{n+1}}{h_{n+1}^2 B} - 2\sqrt{gh_{n+1}^2} - u_R^n + 2c_L^n = -g\Delta t S_0 + g \frac{u_R^n |u_R^n|}{(C_z)^2 R_1^n} \Delta t \tag{6} $$

$$ \frac{Q_N^{n+1}}{h_N^{n+1} B} + 2\sqrt{gh_N^{n+1}} - u_R^n - 2c_L^n = -g\Delta t S_0 + g \frac{u_R^n |u_R^n|}{(C_z)^2 R_N^n} \Delta t \tag{7} $$

$$ Q_N^{n+1} + 2Bh_N^{n+1} \sqrt{gh_N^{n+1}} = P', \quad \text{dimana} \quad P = Bh_N^{n+1} (u_R^n - 2c_L^n - g\Delta t S_0 + g \frac{u_R^n |u_R^n|}{(C_z)^2 R_N^n} \Delta t) \tag{8} $$

From the equation above can be obtained by the value of water depth h because h non-linear equations that can be solved with Newton Raphson method of interpolation.

4.2. Flood Modeling
In flood modeling with numerical analysis method, two parameters that observed, they are flow discharge and water level of upper Citarum River. Based on the purpose of this study is to perform a comparison of the numerical approach by generating an equation solved by FEM. Three things helped to analyze the model the flood in extreme conditions. There are iteration analysis with Force2 program and analysis with the help of HEC-RAS. Results of modeling with HEC-RAS can looked in Figure 2 below. The comparison result depicted in the graph as shown in Figure 3.

The figure 2 shows that the results shown based on simulations of extreme flood events with HEC-RAS 2D modeling. The picture shows the inundation area released by the upper Citarum River when overflowing. The resulting inundation area based on terrain data generated for 2D modeling in HEC-RAS. Based on the analysis, the amount of inundation based on the simulation is 75.26 square kilometers around the river.
The figure 3 shows that the results comparison with numerical analysis approaches. The pictures show the maximum value from simulation among Force2, HEC-RAS, and validation data. From the graph, we know that the change of Q and water level of H have differences between the results from Force2 and HEC-RAS in certain time simulation.

4.3. Flow Validation
Based on the validation of Nash Index of water level obtained the result analysis use Force2 is 0.84 and with use HEC-RAS is 0.76. For discharge data Nash Index obtained the result analysis use Force 2 is 0.80 and with use HEC-RAS is 0.79. The index values is more acceptable.

5. Conclusions
This study has shown that numerical modeling of the flood modeling has become unavoidable works in the hydraulic modeling. There is need for flood inundation models that efficiently and accurately applied over practical scales such as a city or regional flood plain. In this study, based on modeling results with HEC-RAS for 2D modeling, during the extreme flood event in 2010, several areas in the upper Citarum river were almost entirely flood by upper Citarum River overflow, and its inundation area is about 75.26 square kilometers. Comparing two-method show that the FEM analysis with
Force2 programs has the best approach to validation data with Nash Index is 0.84 and HEC-RAS that is 0.76 for water level. For discharge data Nash Index obtained the result analysis use Force2 is 0.80 and with use HEC-RAS is 0.79. Overall, this study showed that optimal design of the flood modeling leads to increase the performance of the flood prevention structures.

Acknowledgments
The author gratefully acknowledged that the research Universitas Sumatera Utara, Indonesia supported for the financial. Thanks to Major River Basin Organization of Citarum, Public Work Ministry, for providing the data and others.

References
[1] Zhou Z, Olabarrieta M, Stefanon L, Alpaos A, Carnielo L, and Coco G 2014 A Comparative Study of physical and Numerical Modeling of Tidal Network Ontogeny Journal of Geophysical Research 119 892-912
[2] Dehdar-behbahani S, Parsaie A 2016 Numerical modeling of flow pattern in dam spillway’s guide wall. Case study: Balaroud dam Iran Alexandria Engineering Journal 55 467-473
[3] Ershadi S, Arasteh M, Tajziehchi M 2013 Numerical Modeling of Flow Pattern Changes in Tidal Inlet of TIYAB Port Journal of Environmental and Earth Sciences 11 691-702
[4] Marsolli R, Orton P M, Georgas N, Blumberg A F 2016 Three-Dimensional Hydrodynamic Modeling of Coastal Flood Mitigation by Wetlands Coastal Engineering 111 83-94.
[5] Aureli F, Dazzi S, Maranzoni A, Mignosa P, and Vacondio R 2015 Experimental and Numerical Evaluation of the Force due to the Impact of a Dam-Break Wave on a Structure Advances in Water Resources 76 29-42.
[6] Leskens J G, Brugnach M, Hoekstra A Y, Schuurmans W 2014 Why are Decisions in Flood Disaster Management so Poorly Supported by Information from Flood Models? Environmental Modelling & Software 53 53-61
[7] Hooke J M 2016 Geomorphological Impacts of an Extreme Flood in SE Spain Geomorphology 263 19-38
[8] Gravenkamp H, Man H, Song C, Prager J 2013 The Computation of Dispersion Relations for Three- Dimensional Elastic Waveguides Using the Scaled Boundary Finite Element Method Journal of Sound and Vibration 332 3756-3771
[9] Fridrich D, Liska R, Wendroff B 2016 Some Cell Centered Lagrangian Lax-Wendroff HLL Hybrid Schemes Journal of Computational Physics 326 878-892
[10] Lu J, Fang J, Tan S, Shu C, Zhang M 2016 Inverse Lax-Wendroff Procedure for Numerical Boundary Conditions of Convection-Diffusion Equations Journal of Computational Physics 317 276-300
[11] Karna T, Baptista A M, Lopez J E, Turner P J, McNeil C, and Sanford T B 2015 Numerical Modeling of Circulation in High-Energy Estuaries: A Columbia River Estuary Benchmark Ocean Modelling 88 54-71
[12] Dehdar-behbahani S, Parsaie A 2016 Numerical modeling of flow pattern in dam spillway’s guide wall. Case study: Balaroud dam, Iran Alexandria Engineering Journal 55 467-473
[13] Butt M J, Umar M, Qamar R 2013 Landslide Dam and Subsequent Dam-Break Flood Estimation Using Hec-Ras Model in Northern Pakistan Natural Hazards 65 241-254
[14] Saksena S, Merwade V 2015 Incorporating the Effect of Dem Resolution and Accuracy for Improved Flood Inundation Mapping Journal of Hydrology Elsevier 530 180-194
[15] Yucel I, Onen A, Yilmas K K, Gochis D J 2015 Calibration and evaluation of a flood forecasting system: Utility of numerical weather prediction model, data assimilation and satellite-based rainfall Journal of Hydrology 523 49-66