American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-10, pp-325-331
www.ajer.org
Research Paper Open Access

Hydrological - Quasi 2D Hydraulic Linked Model for Flood Forecasting

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ABSTRACT: Due to the effect of global warming in recent years, floods have been occurring more seriously with a wider scope in many places in the world. Warning and forecasting the flood situation is an effective solution to initiatively avoid damages caused by floods. In this study, we propose a model linking between the distributed hydrological model and the quasi two-dimensional hydraulic model to simulate the flow on the basin surface and in the river system from the rainfall data which could be the basis for the warning and forecasting of the flooding status of the basin. This linked model has been applied to forecast and warn the floods in the Tich-Bui River basin in the suburbs of Hanoi (Vietnam). The results of the calculation showed the superiority of the linked model and its usability.

KEYWORDS Hydrological Model, Hydraulic Model, Flood Forecasting, Tich-Bui River.

Date Of Submission: 17-10-2018 Date Of Acceptance: 03-11-2018

I. INTRODUCTION

Flooding has been one of the major natural disasters which cause serious losses in people and property in many countries around the world such as Vietnam, Philipine, Japan, China, United State, etc. Researches and suggestions for early flood forecasting have also been taken up by many scientists. One of the trends in early flood forecasting is using numerical method with real data from the study area. Numerical models used in solving this problem are usually one of the following models: A historical data analysis model based on that provides predictions for the future as in Demeritt D. et al. (2010), Tran P. et al. (2010), etc.; the model combines the hydrological model and the artificial neural network model as in Kamp R. G. and Savenije H. H. G. (2007), Nguyen Chinh Kien (2017), etc.; the model uses a combination of hydrological models and hydraulic models which is proposed in this study.

There are now many research groups using combination between hydrological and hydraulic models. In each of the study group, there are different suggestions for combining hydrological models and/or hydraulic models to suit the conditions of the research group as well as the purpose of the problem. Nguyen Tien Cuong and Trinh Thu Phuong (2008) developed a linked model between a 1D hydrological model and 1D hydraulic model to forecast floods in the upstream of the Red river system (which is the biggest river system in the North of Vietnam). The predicted results of this model are quite good compared to other models that have been applied in the same study area. In 2009, H. Van Lai et al. (2009) also used this model (which developed by Nguyen Tien Cuong and Trinh Thu Phuong (2008)) to simulate and predict the large flood in the center of Vietnam. The simulation of the historical flood in 1999 in Hue (World Cultural Heritage) is quite accurate with the real data collected from that flood. Follow this research trend, some other research groups use available hydraulic models and hydrological models, which is commercial or free software, to research flooding problem, such as Liu YB et al. (2005), Biancamaria S. et al. (2009), Nguyen P. et al. (2016) etc.

In this study, we used a distributed hydrological model linking with an extended 1D hydraulic model called a quasi two-dimensional hydraulic model to study flooding capacity of a large downstream area. We then use this model to simulate and forecast the floods in the Tich-Bui River basin in the west of Hanoi, Capital of Vietnam.

II. THEORETICAL BACKGROUND

As discussed above, both hydrological model and hydraulic model in this study are inherited and developed by our group. In particular, the hydrological model was developed on the basis of the MARINE hydrological model (built by the Toulouse Institute for Fluid Mechanics - France). This hydrological model has also been used in many places to calculate and give flood and flash flood forecasting such as M. Alquier et al. (2002), V. Estupina-Borell (2006), etc. This hydrological model has been further researched and developed by the research team of the Institute of Mechanics - Vietnam and is used in practice as in the studies of Nguyen Tien Cuong and Trinh Thu Phuong (2008), H. Van Lai et al. (2009). The quasi two-dimensional hydraulic model is developed on the basis of a 1D hydraulic model developed by a group from the Institute of Mechanics Vietnam.

2.1. Equations and Methods of the Quasi two-dimensional Hydraulic Model:

For a general network there may exist a flow in river network, flow in- or out- storage cells. So one has to deal with three types of equations: partial differential equations for a single river branch, ordinary differential equations for storage cells and equations for hydraulic structures. Apart from these, it is needed to add junction conditions in some locations of the network to keep the flow continuity.

2.1.1. Equations for a single river branch

The free surface flow in a single branch of a river network can be described by the so-called Saint-Venant equations [Ven Te Chow et al. (1998), Nguyen Tien Cuong and Trinh Thu Phuong (2008)] under the assumption of a hydrostatic pressure and uniform distribution of the velocity along the vertical axis.

In practice, the flow in the main channel and flood plain are quite different due to different frictions. So the following types of equations are often used:

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

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_f}\right) + gA_f \frac{\partial Z}{\partial x} + gA_f \frac{Q|Q|}{K^2} = 0 \qquad (2)$$

2.1.2. Equations for storage cells:

$$\frac{dV}{dt} = \sum Q \qquad (3)$$

Where V is the water volume, Q is in- and out- going discharges.

2.1.3. Equation for hydraulic structures and junction conditions

The flow must be conservative, therefore the sum of all discharges must be zero at confluences or tributaries. At hydraulic structures, flow rate is defined by the empirical formula:

$$Q = f(Z_{tl}, Z_{hl}, a) \qquad (4)$$

Where Ztl, Zhl are the upstream and downstream water levels and a is characteristic parameter of structures.

Finally, the initial and boundary conditions must be added.

To get numerical solutions, the considered river network is split into river branches, separated by nodes. A node is a point in a river system where the Saint-Venant equations are not valid. A confluence or tributary is a node. For a hydraulic structure in rivers, it is associated with two nodes- upstream and downstream due to different water levels.

The numerical method is based on the implicit 4-points Preissmann method for river branches instead of high resolution numerical methods, implicit finite difference scheme for storage cells and linking discharges of hydraulic structures.

2.2. Equations and Methods of Hydrological Model:

2.2.1. Mesh, discretization, integration method

The modeling of the surface runoff follows an Eulerian approach of the problem by solving the continuity equation on a structured grid. It takes into account the overland flow and the ground infiltration. Square meshes are used for the discretization of the area catchment. Characteristic values (altitude, water depth) are variable from one mesh to another. Integration method is based on finite volume method. Each mesh has two different water heights: one resulting from the overland flow and the second coming from the ground infiltration.

2.2.2. Surface runoff modeling

The overland flow modeling is done by solving mass conservation in each mesh and with the calculation the velocity of the surface runoff. The mass conservation equation is the following (where V is volume, u the velocity and P_0 the source term modeling precipitation):

$$\iint_S \frac{\partial V}{\partial t}.dS + \oint_\Gamma V.\mathbf{u}.\mathbf{n}.d\Gamma = \iint_S P_0 \quad (5)$$

Surface runoff velocity comes from the diffusive wave equation derived from St Venant equation:

$$\|\mathbf{u}\| = \sqrt{slope}.\frac{H^{2/3}}{Manning} \quad (6)$$

2.2.3. Infiltration modeling

The Green & Ampt Infiltration model has been implemented in MARINE. The watershed is exposed to a spatially distributed rainfall with a time variable intensity. For a given computational cell of the watershed, the soil is supposed to be uniform as well as the water content. The potential infiltration rate is calculated using the following equation derived from the Darcy law:

$$f_t = K\left(\frac{\psi(\eta - \theta_i)}{F_t} + 1\right) \quad (7)$$

ψ is the suction force, K the hydraulic conductivity, η the porosity, and θ_i the initial water content, and F_t the cumulative infiltration at time t.

III. HYDROLOGYCAL-QUASI 2D HYDRAULIC LINKED MODEL FOR SHORT TERM FLOOD FORECASTING IN THE TICH-BUI RIVER BASIN

The linked model was established for the Tich-Bui River basin in the west of Hanoi, capital of Vietnam. The area of the basin is over 2000 km^2. The study area is delimited by the Da river in the west, the Red river in the north, the Day river in the east, and the confluence between the Tich-Bui river and the Day river in the south (at the location of BaTha hydrological station). The location of this basin is shown in Figure 1.

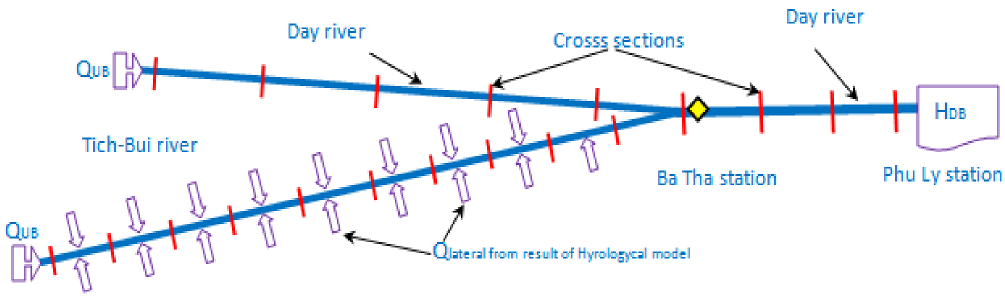

Figure 1: Hydrological and Quasi-2D Hydraulic Linked model

3.1. Input data and Materials

The data used for the hydrological model in this study includes: Digital elevation model (DEM) of the Tich Bui basin with a cell size of 30m; landcover map scale 1:50 000; Soil map scale 1:50 000; Rainfall data and forecast of 8 stations (Hoa Binh, Ba Vi, Trung Ha, Viet Tri, Son Tay TV, Son Tay, Hoai Duc, Ba Tha) in the basin. The calculated result of the hydrological model is the flow of water into the Tich-Bui River system.

The data used for quasi two-dimensional hydraulic model includes data for 1D hydraulic model as well as data for the storage-cell system and the linked works. It consists of 450 crosssections along 110km length of the Tich-Bui river. The branch of the Day river is about 180km long with 78 cross sections. All the flows calculated from the rainfall data flow into the Tich-Bui river; the storage-cell system is also linked to the Tich-Bui river. Therefore, the number of the cross sections of the Tich-Bui river should be very detailed. The Day river mainly operates in water transferring, does not connect to the storage cells and does not receive the water from the Hydrological model thus the number of the cross sections is less. The storage cell system uses topographic maps combined with an elevation map with scale 1: 10000. The boundary between the storage cells is taken from the traffic system (with designed elevation) and the actual geomorphology of the basin which is possible to be flooded.

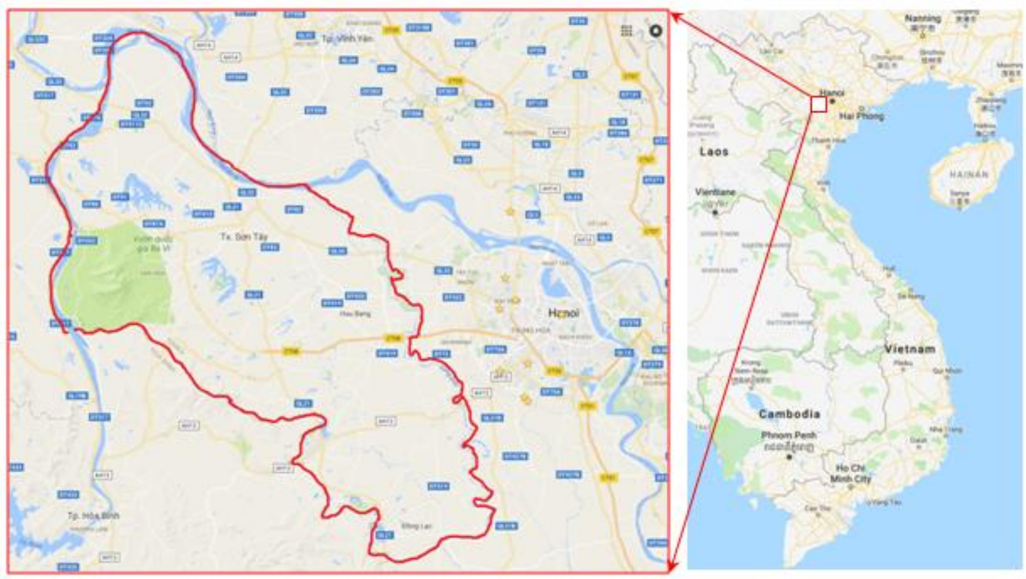

Figure 2: Location of the Tich-Bui river basin (source: Google maps)

3.2. Parameters correction for the Linked model

To correct the set of parameters for the linking model to calculate for the Tich Bui river basin, the research group used historical real data of this basin to calibrate the parameters of the model.With the real historical rainfall data, the calculating results of water levelsat the Ba Tha hydrological station need to be in line with the actual water levels.

In this work, we used the database of two floods to calibrate the model, which contains:

- The first flood occurred from 26 August 2014 to 15 September 2014.
- The second flood occurred from 28 July 2015 to 11 August 2015.

The results of the calibration by two floods above are shown in Figure 3 and Figure 4. These Figures show that the calibration results are close to the real data, especially the simulation results of the peak of the floods. In general, the calculation results of the flood in 2014 are better than the results of the 2015 flood. The graphs also show that the error between the calculations and the real measured dataoften occurs when the water levelsare low. One of the causes of this error is probably the effects of the reservoirs in the basin. When heavy rains last for a long period of time, theriver water levels rise; these reservoirs are full of water then free overflows. When the rainsare small or interrupted, a part of the rainfall water is stored in the reservoirs that cause a shortage of water. The model does not reflect this problem.Therefore, when the river water levels are low, the calculation results tend to be larger than the actual value.

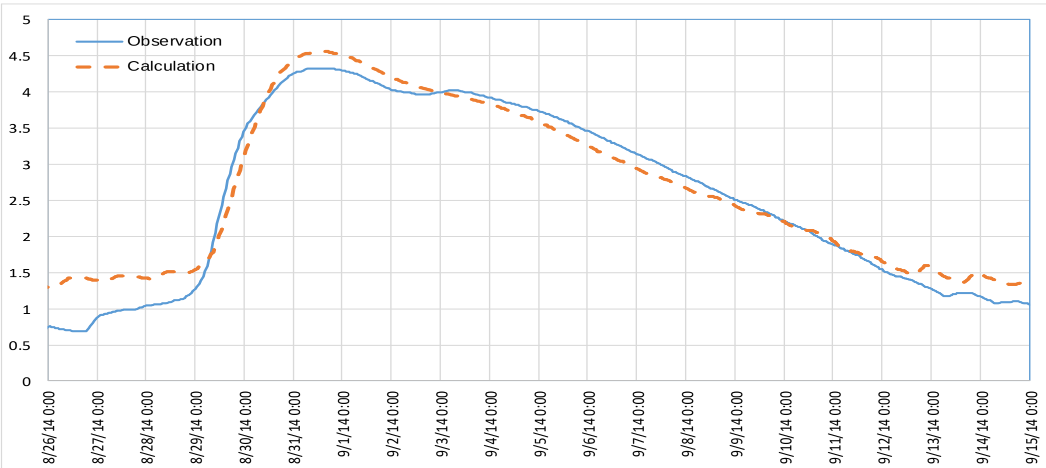

Figure 3: Results of the model calibration after the flood in 2014

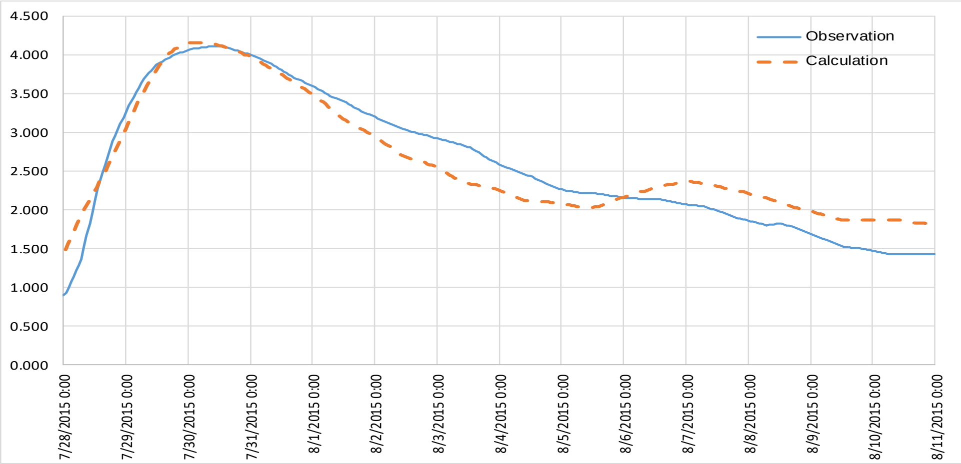

Figure 4: Results of the model calibration after the flood in 2015

3.3. Application for flood forecasting in the Tich-Bui river basin

Using the set of parameters which are obtained aftercalibrating the model by the historical real data (the flood in 2014 and the flood in 2015), we applied this model to forecast the water levels at Ba Tha hydrological station and forecast the flood in the basin of this river in 2016 and 2017.

The forecasting water levels by the model at Ba Tha hydrological station 24 hours before the floods in 2016 and 2017 are shown in Figure 5 and Figure 6 below:

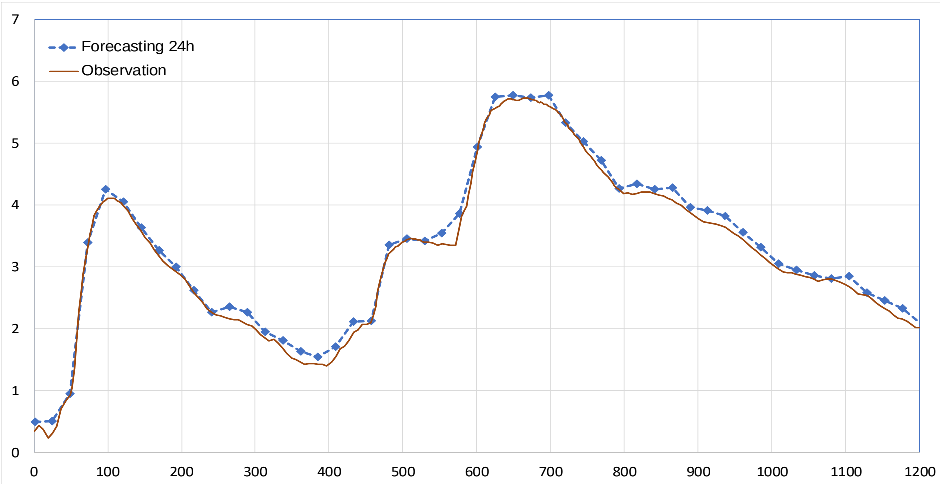

Figure 5: 24-hour predicted water levels at Ba Tha hydrological station in 2016

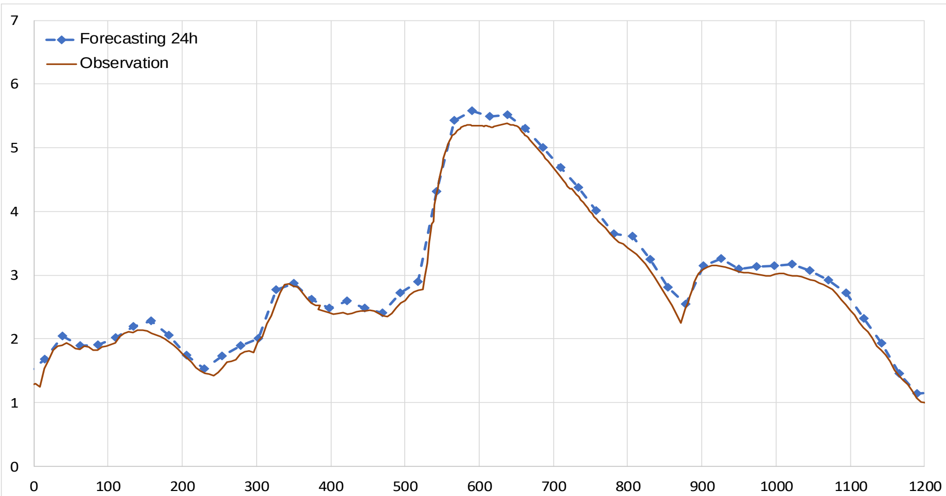

Figure 6: 24-hour predicted water levels at Ba Tha hydrological station in 2017

The 24-hour forecasting water levels at Ba Tha hydrological station in 2016 and 2017 show that the model can accurately predict the water levels in the river in case there was no overflowing or dyke break.

In case of overflowing at the dyke, the model will indicate the overflowed area, overflowed time, the flood depths and the flood area.

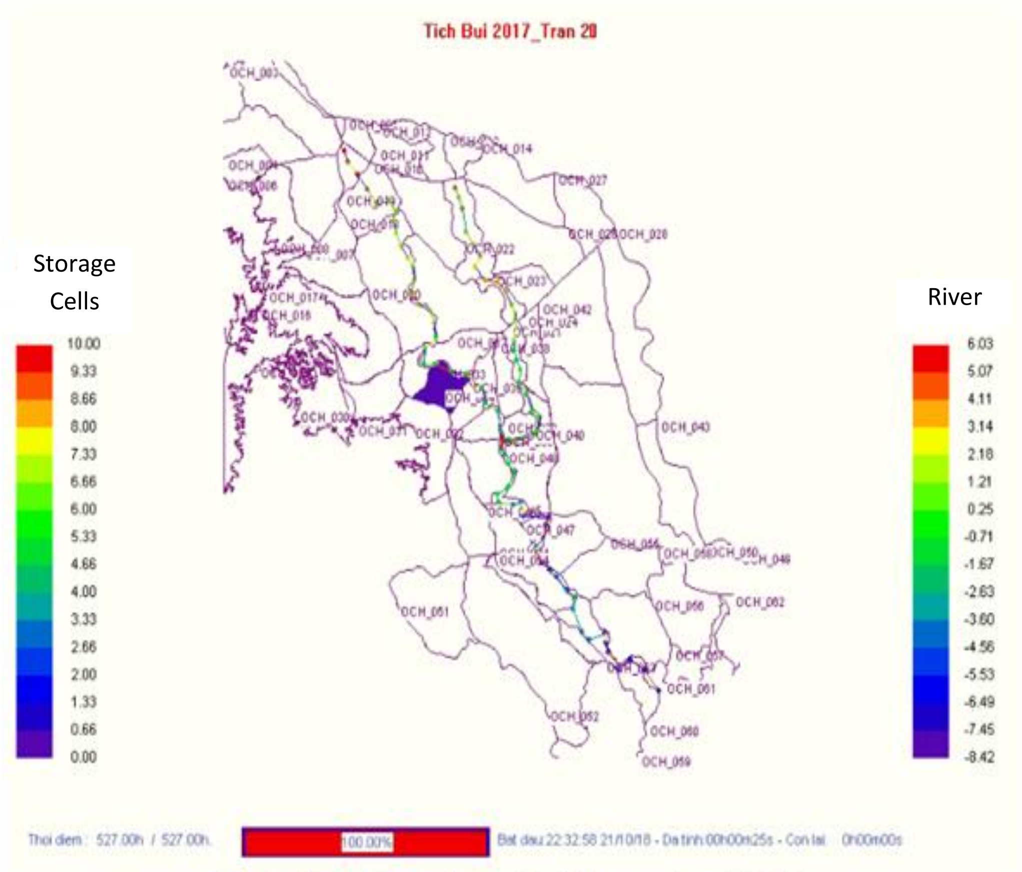

Figure 7: Flood forecasting results of the second flood in 2017

Figure 7 shows that the model figured out a flooding residential area by the water overflowed from the river. This result has also been consistent with the reallocation of the overflowed and flooded area in the history. However, the calculation flooding depth and flooding area are quite different from the reality of the flood in 2017. Thisdifferenceis because the overflow water madeerosion and broke the dyke. As a result, the water level in the river and the water level in the flooding residential area are not accurate quantitatively.

IV. CONCLUSION

A Hydrological - Quasi 2D Hydraulic linked model has been developed as a tool for flood warning and forecasting. This model is suitable for calculations of basins with large area and areas lacking topographic data to use in a fully 2D hydraulic model.

This linked model has been applied to forecast floods and give flood warning for the Tich-Bui river basin in the west of Hanoi, capital of Vietnam; and has shown good results. The results of the forecast calculation reflect the true flood situation in this river basin. The calculation errors are mainly due to the effects of the artificial works (such as the reservoirs) and the incidents (such as dyke breaks).

This linked model has proved its advantages over the 2D hydraulic model because it does not require detailed terrain data and has a fast calculation time. This is suitable with the actual conditions of developing countries and regions.

To get a better ability of flood forecasting, it is necessary to continue developing some more modules that may limit the effects of artificial structures as well as the destroying incidents such as dyke breaks.

ACKNOWLEDGMENTS

This research was supported by the Hanoi's Project No. 01C-07/01-2016-3.

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Cuong T. Nguyen "Hydrological - Quasi 2D Hydraulic Linked Model for Flood Forecasting "American Journal of Engineering Research (AJER), vol. 7, no. 10, 2018, pp. 325-331