

Application of hydraulic model MASCARET for flow simulation of the Hong - Thai Binh River system

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Abstract— The Hong–Thai Binh River system is the second river system in Vietnam (after Mekong River system) and plays an important role in socio-economic development of the country. In the recent years, big floods frequently happened in Vietnam, and flood disaster causes massive losses of human life and immense damages. Also, this river network and the flow hydrodynamic is very complicated. On that basis, the study of specific characteristics about the flow regime of this river basin is necessary to provide valuable information for better management and planning of this river system.

In this work, the authors use a one-dimensional hydraulic model to study the hydraulic characteristics of the Hong-Thai Binh River system. The calibration and verification results showed the high reliability of this model, it would be very useful in flood controlling and mitigating for whole area.

Keywords— The Hong–Thai Binh River system, one-dimensional hydraulic model, hydraulic characteristics.

I. INTRODUCTION

The Hong River occupies a large area from the Northwest high mountains to the Tonkin Gulf - a densely populated area with great economic potential. The river basin is long and narrow upstream, expanding in the Vietnam part (Fig. 1). High mountains are strongly divided, creating terrain that receives wind from the sea, causing heavy rain and abundant currents [1].

The Thai Binh River is located in the northeastern region of the north, the west and the north borders the Hong River. This basin is made up of three rivers: Cau, Thuong and Luc Nam river. The terrain in the Cau River basin gradually lower from north to south, while in the Thuong and Luc Nam River basins, they gradually lower from the northeast - southwest. The average elevation of the Cau River and Thuong River basins are approximately 190 m while Luc Nam River is higher (207 m).

The flood is one of the natural disasters that can cause great loss of life and property to the population areas living in the basins of river systems. Therefore, research on flood prevention and control measures is needed. This problem is being researched and implemented by many agencies and organizations. In the recent years, due to the influence of global climate change, the evolution of floods in the Hong-Thai Binh River system has also shown extreme signs and increased. Therefore, it is necessary to have research to solve this problem in order to be able to establish a flood warning and forecast system to reduce damage caused by this disaster.

Nowadays, one of the important methods that has been applied is the modeling method with hydraulic models

describing and predicting floods. Thanks to the strong development of information technology, many hydraulic software has been used as a key tool in flood forecasting and control in river basins.



Fig. 1. The Hong-Thai Binh River system

The advantage of one-dimensional hydraulic models is used for research over a large spatial scale for one or more river systems. Besides, the Hong-Thai Binh River system is a large river basin with extremely complex river connections. Therefore, choosing a hydraulic model to simulate river flow is an important basis for accurately

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assessing and making operational decisions in emergency situations due to the effects of climate change in the future.

In the world, research and application of hydraulic models has been used quite commonly. Many models have been built and applied for reservoir forecasting, flood forecasting for river systems, and for flood prevention planning. Some models have been practically applied in simulating and forecasting flow for river basins. Most of these numerical models are commercial or freeware.

MASCARET modeling framework is a set of numerical codes simulating one-dimensional (1-D) hydro-environmental problems through a network of open channels. The user interface FUDAA-MASCARET manages the input data, allocation of parameters, running of simulations and viewing outputs. MASCARET can be easily compiled as a dynamic library, offering special interfaces to be used with three main steps: Initialization, Run and Finalization of the calculation.

With these features, MASCARET can be coupled or integrated to other softwares without requiring significant efforts [3]. However, access to this hydraulic model is limited in Vietnam. Hence, the main aim of this paper is to provide valuable information of MASCARET tool in flow simulation of the study area.

II. METHODOLOGY

A. MASCARET modelling framework

MASCARET modeling framework is a set of numerical codes simulating one-dimensional (1-D) hydro-environmental problems through a network of open channels. This modeling package has been developed by Electricite de France-Recherche & Developpement (EDF-R&D) in collaboration with 'Centre d'Etudes Techniques Maritimes et Fluviales (CETMEF) over more than 25 years. MASCARET is suitable for a wide range of engineering and environmental applications, from calculating simple backwater profiles to model networks of open channels including floodplains and storage areas. Applications include flood risk assessments and mapping, developing management plans, flood alleviation scheme designs, dam-break flows, and water pollution management. Since July 2011 the software package is worldwide distributed as an open-source project for the benefit of students, engineers and researchers.

The wellknown shallow water equations can be solved with three different computational kernels. The choice of the specific kernel depends on the case study: steady or unsteady, with subcritical and/or supercritical flows.

1) SARAP Kernel

This kernel is for steady cases with subcritical, critical and supercritical conditions. The 1-D equations are solved in one step with a finite difference scheme where time derivatives are cancelled. A special treatment is performed for the shock capturing with the solution of a non-linear equation within the supercritical region in order to determine the flow level at the point of the supercritical-subcritical transition. The validity of the shock position is checked with the principle of conservation of momentum [2].

SARAP is extremely fast due to the need of only one iteration to solve the problem. It is recommended in order to quickly find correct initial conditions for the two others unsteady kernels, or when a large amount of calculations is

necessary for a parametric study (model calibration, optimisation, incertitude study, etc.).

2) REZO Kernel

REZO implements the classical finite difference Preissmann scheme for the unsteady subcritical solution of the shallow water equations [4]. It is implicitly coupled with a code of water storage areas in order to take into account floodplain inundations. This code is extremely robust and fast under subcritical conditions for operational use.

3) MASCARET Kernel

The last hydrodynamic computational kernel is based on a well-balanced finite volume Roe scheme. It has been designed to perform well with the simulation of dam break waves for EDF needs. It offers special capabilities comparing to other codes like the modelling of some non-hydrostatic waves, or the modelling of junctions with 2-D elements. In this last case, MASCARET implements a simplified 1-D-2-D coupling. The junction is modelled by a 2-D representation with 12 cells (Fig. 2):

- 6 triangles defining an hexagon, models the junction itself and can be defined as exchange cells;
- 6 quadrilaterals covering the 1-D domain for the overlap coupling. The junction hexagon has a geometry similar with the real one. It is built using the direction of reaches and the width of valleys given by the user. This should lead to a good discharge repartition in the different reaches.

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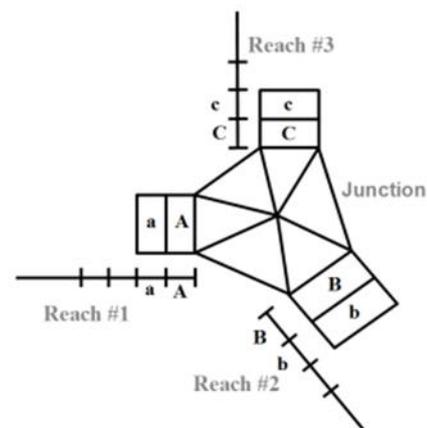


Fig. 2. Overlap coupling for the junction

MASCARET kernel is suitable for every kind of computational fluid dynamics. One will only take care of time step restriction due to the Courant-Friedrichs-Lewy condition if the explicit version of the time discretization is chosen.

B. Equations

The well-established Saint-Venant equations of a reach are used [5]:

The continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial S}{\partial t} = q_l \quad (1)$$

with: $Q(x, t)$: the flow ($m^3 \cdot s^{-1}$); $S(x, t)$: the area (m^2); $Z(x, t)$: the elevation of the free surface (m).

The momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\beta \frac{Q^2}{S} \right) + gS \left(\frac{\partial Z}{\partial x} + J \right) = \gamma_l \quad (2)$$

with g : the acceleration of gravity ($m \cdot s^{-2}$).

The continuity equation relates to the conservation of the flow, the momentum equation corresponds to the fundamental equation of dynamics: the first member represents the acceleration of a volume of water; the second member represents the sum of the forces applied to it.

When there is no lateral inflow: $q_l = \gamma_l = 0$. In the case of a lateral inflow: the inflow is considered perpendicular to the flow and does not bring any momentum: $\gamma_l = 0$; or the inflow modifies the momentum equation: $\gamma_l = \frac{Q}{S} q_l$.

The term gSJ relates to the effect of friction: J is a dimensionless number, representing the average rate of the energy dissipation. It depends on the flow, the hydraulic characteristics of the river and of course, on the roughness coefficient. It is calculated with the Strickler relation:

$$J = \frac{Q^2}{K_m^2 S^2 R^{4/3}} \quad (3)$$

or:

$$J = \frac{Q^2}{D^2} \quad (4)$$

with: K_m the Strickler's roughness coefficient; R : The hydraulic radius; D : The conveyance.

The dimensionless coefficient β results from the variations of the actual flow velocity in a section. These variations would otherwise be ignored as only the average velocity is considered in the one-dimensional equations. The definition of β is:

$$\beta = \frac{S}{Q^2} \int V^2 DS \quad (5)$$

with: $\beta = 1$ in a single channel

The boundary conditions in subcritical regime usually are:

- A discharge imposed at the upstream boundary;
- An elevation or, for unsteady flow a stage-discharge relationship, imposed at the downstream boundary.

In unsteady flow, it is possible (from a numeric point of view) to impose any types of boundary conditions (imposed elevation, discharge or a relationship between elevation and discharge) for both upstream and downstream boundaries. However, they have to be coherent to ensure that the algorithm runs successfully.

III. SET-UP ONE-DIMENSIONAL (1D) HYDRAULIC MODEL

A. Data collection

1) Topographic data

In order to set up the model, the Hong-Thai Binh River network is schematized by 67 reaches, 37 junctions with 928 cross-sections. Fig. 5 shows the schematic of the main rivers, upstream reservoirs, and hydrological stations which are used for model's calibration and validation.

2) Hydrological data

The Hong - Thai Binh River system in MASCARET includes, limited by the upper boundaries from Hoa Binh reservoir (Da River), Tuyen Quang (Gam River), Thac Ba (Chay River), Yen Bai (Thao River), Ham Yen (Lo River), Thai Nguyen (Cau River), Cau Son (Thuong River), Chu (Luc Nam River) to downstream coastal rivers.

The study area has a coastline extending from Quang Ninh to Ninh Binh. The downstream border is established at river estuaries including: Cua Day, Ninh Co, Ba Lat, Tra Ly, Thai Binh, Van Uc, Lac Tray, Cua Cam, Da Bach.

The measured data in 2015, 2016, 2017, 2019, 2021, 2022, 2023 are carried out.

B. Model set-up

The components used for the calculation of the model include: Computation Kernel; Hydraulic network; Boundary; Mesh; Initial conditions; Temporal parameters; General parameters; and Output parameters.

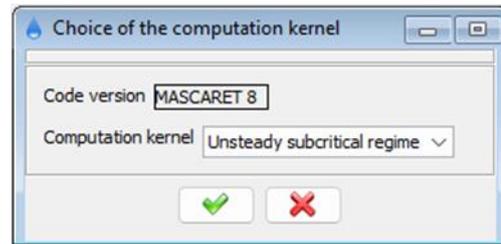


Fig. 3. Selection of the computation kernel in MASCARET

The reaches and junctions are built in hydraulic geometry. Each reach has the number of cross-sections input, respectively (Fig. 4).

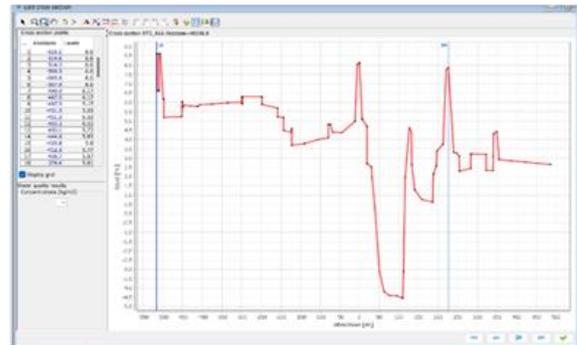


Fig. 4. Cross-sections data

The boundary conditions (Fig. 6) are set on the open boundaries: The upstream boundaries are the measured discharge at hydrological stations; The downstream boundaries are the observed water level boundaries at Cua Cam, Kien An, Quang Phuc, Dong Xuyen, Dong Quy, Ba Lat, Phu Le and Nhu Tan hydrological station.

In this paper, the computation method for mesh is based on the physical cross-sections. This means entered cross-sections as computation cross-sections.

A. Calibration results

The comparison between the collected and simulated data is shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10. The value of NSE is 0.95, 0.86, 0.82 and 0.96, respectively. So, it indicates the relatively agreement of the simulated hydrographs to the observed.

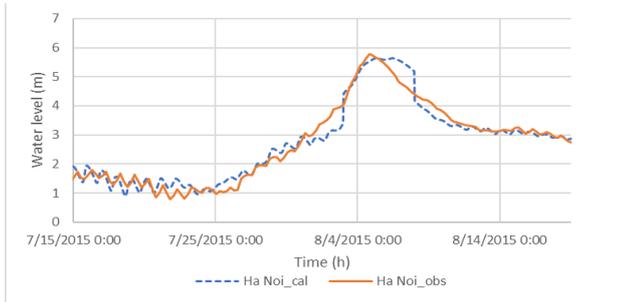


Fig. 7. Calibration of water level at Ha Noi station, 2015

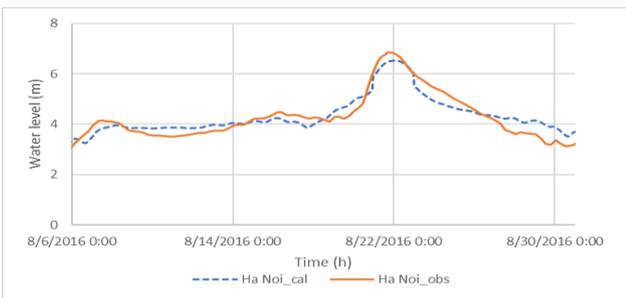


Fig. 8. Calibration of water level at Ha Noi station, 2016

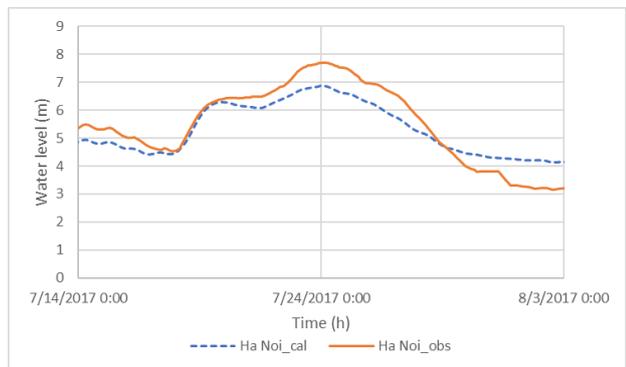


Fig. 9. Calibration of water level at Ha Noi station, 2017

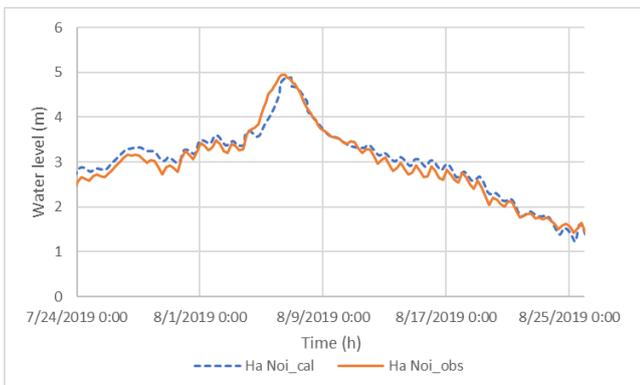


Fig. 10. Calibration of water level at Ha Noi station, 2019

B. Validation results

Based on the calibration results, it is clear that the reliability of MASCARET for flow simulation of the study area. From that, the next step is applied by validating calculations. The performance for validations as presented in Fig. 11, Fig. 12 and Fig. 13. The Nash Index efficiency in these calculations is 0.8, 0.82 and 0.81, respectively (Table II). Both calibration and validation results were found satisfactory, thus providing good agreement between measurements and simulations for the water level. So this hydraulic model is suitable in this research.



Fig. 11. Validation of water level at Ha Noi station, 2021

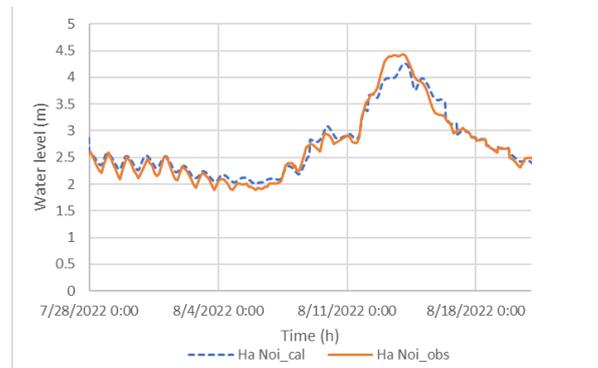


Fig. 12. Validation of water level at Ha Noi station, 2022

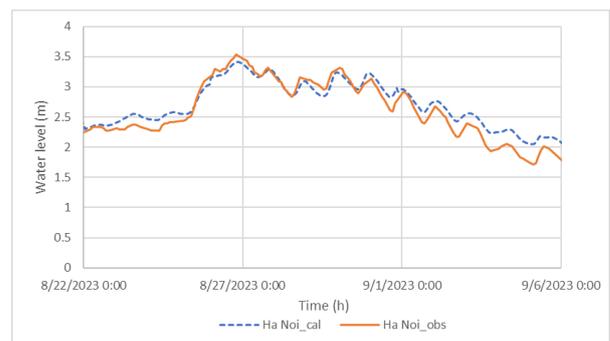


Fig. 13. Validation of water level at Ha Noi station, 2023

From the calculations of the water level by the model, it can be found that the flow regime has changed clearly in the recent years. In particular, in the periods 2015-2017, the water level at Ha Noi station could rise as high as approximately 8 m. Compared to the years 2019, 2021-2023, the water level reduced from 5 m to less than 3 m (in 2021) in the flood season.

TABLE II. NSE INDEX OF CALCULATION SCENARIOS

Year	Calibration				Validation		
	2015	2016	2017	2019	2021	2022	2023
NSE	0.95	0.86	0.82	0.96	0.8	0.82	0.81

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V. CONCLUSION

MASCARET model has been calibrated and validated using available observed data at Ha Noi hydrological station in the Hong-Thai Binh River system for many years. The calibration procedure to achieve the satisfied results and showed that the model had an excellence performance.

Based on validation results in the last 3 years (2021-2023), it is shown that the problem of river bed erosion leads to a lowering of the water level. Also, the illegal sand exploitation is one of negative effects in changing the river bed. The imbalance of sediment causes river bank erosion, directly affecting people's lives, socio-economic development, and riverside constructions, causing difficulties to supply water for agriculture and transportation.

Human activities, mainly the increasing sand exploitations have influenced to the flow behavior of the Hong-Thai Binh River system over the past few years. This paper provides scientific basis for further researches to provide useful information for management and planning of this river system.

ACKNOWLEDGMENT

This paper is funded by the research project from Institute of Mechanics, Vietnam Academy of Science and Technology, code VCH.ĐTT.02/2023.

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