Transport and Communications Science Journal

MIKE FLOOD APPLICATION FOR FORECASTING INUNDATION ISSUES: CASE OF DUC MY BRIDGE AREA

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ARTICLE INFO

TYPE: Research Article
Received: 14/07/2023
Revised: 20/08/2023
Accepted: 12/09/2023
Published online: 15/09/2023
https://doi.org/10.47869/tcsj.74.7.6

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Abstract. The Duc My Bridge is situated approximately 8 km downstream from the Ea Krong Rou reservoir, within the Dinh River system in Khanh Hoa province. Over the years, the region has been experienced heavy rainfall and flooding, leading to elevated flood levels and alterations in the hydraulic regime downstream of the reservoir. These changes are particularly exacerbated by the impacts of climate change. The Ea Krong Rou reservoir belongs to the group of small reservoirs. This is also the type with the highest rate in Vietnam and is more prone to accidents in the rainy season than other types, so the downstream areas are also greatly affected. The article sets up the input parameters for the Dinh River flood plain using the modelling tool MIKE-FLOOD, which integrates the 1-D MIKE-11 model with the 2-D MIKE-21 model. The results show six scenarios (SC1; SC 1C, SC 2, SC 2C, SC3, SC 3C) with very different flood inundation mapping in Duc My Bridge area and other locations. In addition, the paper also determines the degree of concordance between calculated and observed data. Notably, the roughness coefficient is adjusted in the study area to ensure reasonable results.

Keywords: Duc My bridge, Ea Krong Rou reservoir, MIKE 11, MIKE FLOOD, MIKE-21.

1. INTRODUCTION

There are more and more extreme rain events in particular climate change context, along with the impacts of sea level rise on the tides that increase the water level of canals and rivers; flooding has occurred heavily. The Ea Kron Rou reservoir, built in 2007, belongs to Cai - Ninh Hoa river system, Nha Trang, belonging to a group of small reservoirs. The Dinh River system belongs to Cai - Ninh Hoa River system, including the Dinh, Tan Lam, Suoi Trau, Cau Lam, and Da Han Rivers and three reservoirs: Ea Krong Rou, Suoi Trau, and Da Ban as shown in Fig 1. The hydraulic regime of the river system interacts mutually and affects the flood drainage process at the Ha Lien - Ninh Hoa outlet.

Two measures have been employed to mitigate flood damages: structural and non-structural interventions. Flood hazard mapping is a non-structural measure and can be put to a broad spectrum of use to reduce flood damage effectively. To evaluate the inundation map of the bridge area and the downstream of the reservoir, the paper simulates the model in the case of a bridge and without a bridge. The reservoirs operate under different scenarios, including the dam failure scenario. The article has set up the parameter configuration of the MIKE model (NAM; 11 and 21) [1-4] to evaluate the change in different scenarios. These scenarios include:

1) Scenario 1 - Complying with regulations on reservoir operation during the annual flood season (involving the participation of The Duc My Bridge SC 1C, in contrast SC1);

2) Scenario 2 - Da Ban Lake, Eakrong Rou Lake, Suoi Trau Lake operate according to regulations, Ea Krong Rou Lake has problems (similar to SC 2C and SC 2);

3) Scenario 3 - Simulation of dam failure at all 3 lakes (Da Ban lake, Eakrong Rou lake and Suoi Trau lake) (similar to SC 3C and SC3) as presented in Table 1.

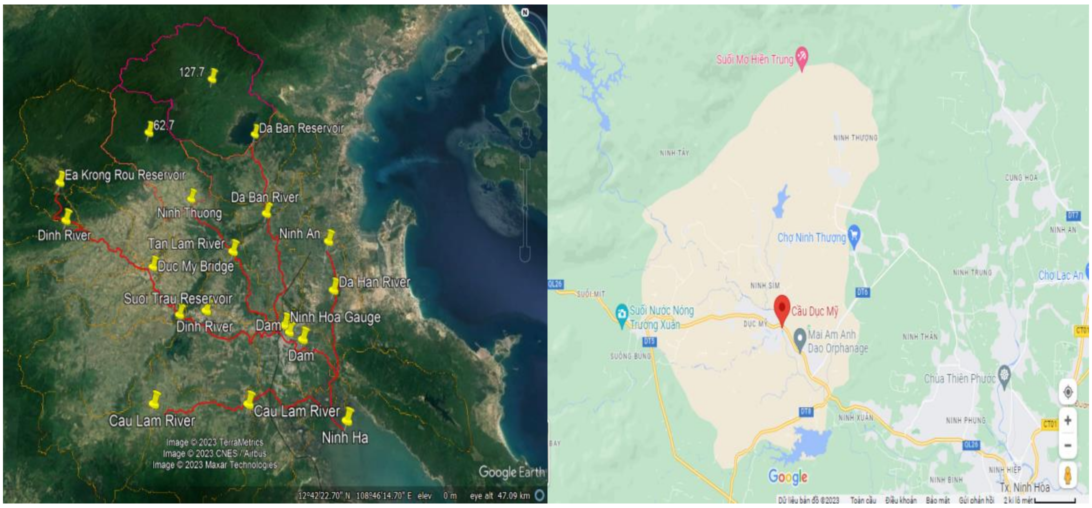

Figure 1. The Cai river system - Ninh Hoa, Khanh Hoa.

Table 1. Scenarios in MIKE packages.

Scenario	Scenario of participation of bridge	Flood/Rain frequency	Tide frequency	Scenario
SC 1	SC 1C	1% 1%	5%	According to regulations on coordination of operation of reservoirs in the annual flood season.
SC 2	SC 2C	1% 1%	5%	Da Ban, Ea Krong Rou and Suoi Trau Reservoir operate according to regulations. A dam failure occurred at Ea Krong Rou Reservoir.
SC 3	SC 3C	1% 1%	5%	Dam failure occurs at all 3 reservoirs, Da Ban Reservoir, Eakrong Rou Reservoir and Suoi Trau Reservoir.

To prepare flood hazard maps by a hydrologic-hydraulic approach, the flood depth, area, and duration of flood inundation for the peak level of a specific return period are determined using hydrologic and hydraulic models. Many mathematical models have been developed for floodplain delineation, flood inundation, and flood simulation, which may be used as a tool to delineate floodplain zones bordering the rivers and calculate the associated risk considering the hypothetical floods of various return periods.

The numerical models using one-dimensional (1D) approximation were commonly based on the finite difference method [5,6] and the finite element method [7,8]. Nevertheless, the finite difference method is still popular because of comparatively less computational effort. Many available commercial software packages, like DWOPER, FLDWAV, MIKE-11, ISIS, SOBEK (1D), etc., have been used extensively for dynamic 1D flow simulation in rivers. One-dimensional models need to provide comprehensive information about the flow field of extensive flood inundation. Therefore, attempts have been made to model the two-dimensional (2D) nature of floodplain flow. The first attempt in this direction was a quasi-two-dimensional approach [6,9] that focuses on mass transfer between cells and is not a fully dynamic simulation of 2D flow, but is satisfactory for slow-rising floods. Subsequently, various numerical schemes have been utilized to solve the 2D flow equations. Many types of commercial software are available for 2D flow simulation, but two of the most widely used are MIKE-21 [1,2] and TELEMAC-2D [10,11]. MIKE-21 is based on the finite difference methodology, whereas TELEMAC-2D relies on the finite element methodology. While 1D models are simpler, 2D models require substantial computational resources; therefore, efforts have been made to couple 1D river flow models with 2D floodplain flow models. These 1D-2D coupled models offer significant advantages for real-time simulations of flooding events due to their relatively shorter computational time compared to full 2D models.

This approach simulates the flow in the main river channel using the 1D equations. For water spilling over the riverbanks onto the floodplain, the 2D equations are solved using numerical methods. The connection between the two types of flow is typically established through a mass conversion equation. MIKE-21 has been dynamically integrated with the MIKE-11 model, forming a single package called MIKE-FLOOD, developed at the Danish Hydraulic Institute (DHI) in Copenhagen, Denmark [12]. Although these packages are commercially available, there are several non-commercial packages designed for research purposes; among them, LISSFLOOD-FP is quite popular.

This study involves the application of MIKE-FLOOD to the Duc My Bridge within the Dinh River floodplain. The objective is to implement inundation assessment methodology and present a reliability analysis framework to investigate flood vulnerability through a real-world bridge case study."

2. MATERIALS AND METHODS

2.1 Materials

Meteorology

The article utilizes data from 13 rain gauges, out of which only eight rain gauge stations are in operation. The measuring stations are usually concentrated in the lower part of the rivers. In the upstream, the density of the station network is down. Nha Trang station on meteorological factors such as temperature, humidity, and evaporation has been from 1977 to the present, and daily rainfall data is from 1958 to the present.

Topography, cross section

The paper uses topographic data from the topographic map of 1/10,000 of Khanh Hoa province made by the Ministry of Natural Resources and Environment and used to build the Digital Elevation Model (DEM) with 10x10 meters resolution using GIS tools. The coordinate system used in this setting is the VN-2000 national coordinate system, the axis meridian 108^o with the national elevation of Vietnam. Below is a diagram of cross-sections of the Dinh River system using MIKE 11 model in 2010, 2019.

The Duc My Bridge

Ninh Hoa town is located at the junction of National Highway 1A and Highway 26 to Buon Ma Thuot, Dak Lak province. The town center is 33 km from Nha Trang City, 27 km from Van Gia town, Van Ninh district, and 164 km from Buon Ma Thuot. Ninh Hoa town is also a place with a convenient traffic position in economic exchange and development with the North-South railway passing through and with important seaports in the south of Van Phong Bay, which are significant in service development: oil transshipment, general port for transporting goods and tourists. The Duc My Bridge within Ninh Sim Commune, Ninh Hoa town, whose topography is oblique compared to the center of National Highway 26, so the Duc My Bridge centerline is diagonally angled with the river flow center at an angle of about 45^o. Bridge length L = 127m including ten spans, each span 12m, I-beam of a composite concrete slab. The height of the bridge deck is 20.57m lower than the path of the two ends of the bridge. According to a hydrological survey, the highest flood year was 1986, with a flood level of 21.17m, and 2008, with 20.67m as shown in Fig 2. During the rainy season, water levels rise, and dam discharges from the Ea Krong Rou reservoir result in flooding of the bridge deck and both pathways.

Figure 2. The Duc My Bridge before and after the 2008 flood event.

River network

In the present study, the layout of MIKE-11 river network was prepared by digitizing the scanned and geo-referenced topographical map of the study area in the MIKE-11 network editor tool, as shown in Fig 3. The spacing interval between consecutive digitized points was kept finer (about 150 meters) to accurately represent the river network.

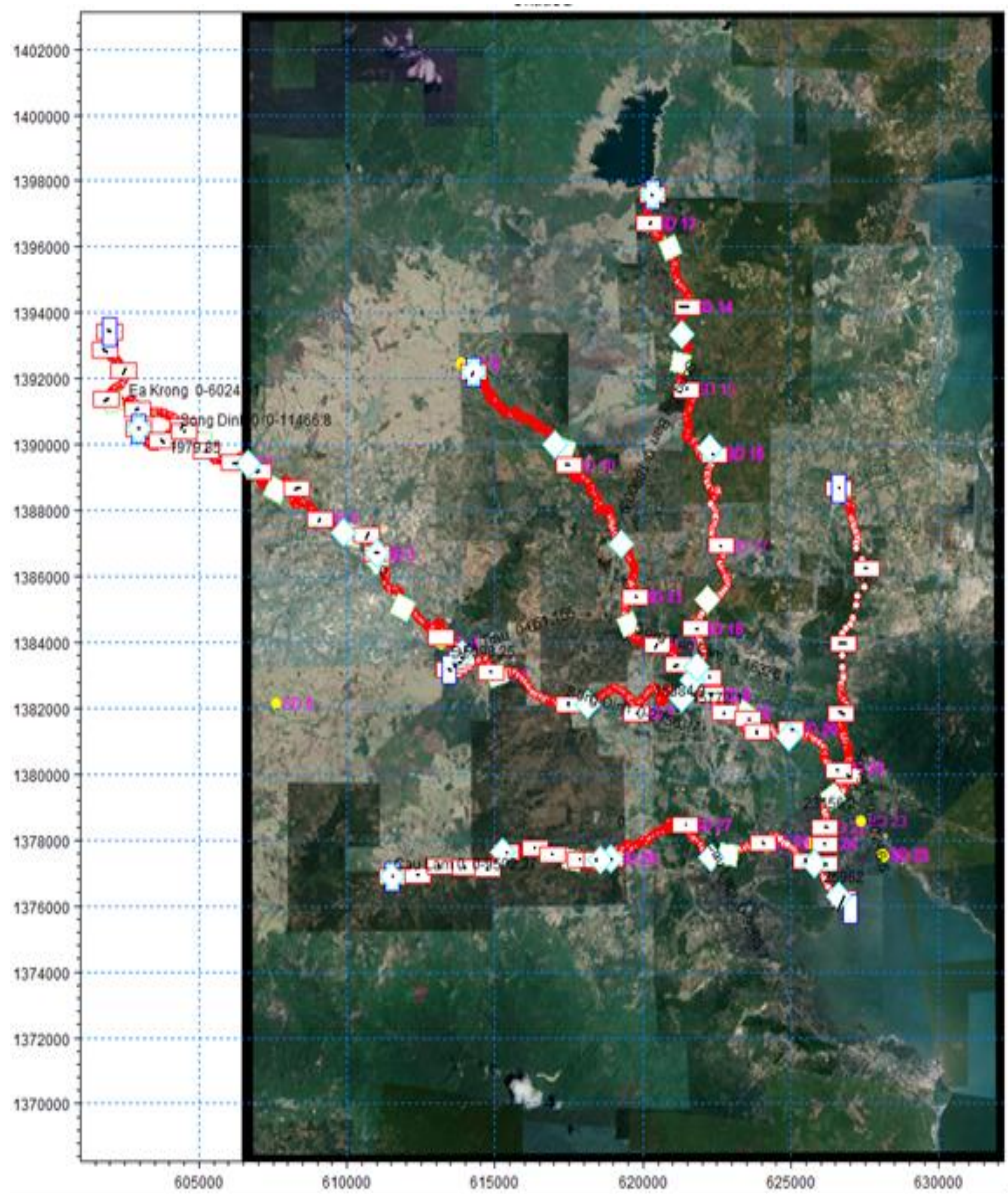

Figure 3. The MIKE-11 network of The Dinh river system.

Cross sections

The cross sections were provided for river reach at an interval of 3 to 440 km. The x-z coordinates (from a left bank) were entered as raw data in the cross-section editor. The raw data were then automatically processed into a format suitable for hydrodynamic calculations. The hydraulic parameters, cross-sectional area, hydraulic radius and storage width were calculated for different water levels between minimum and maximum. Fig 4 illustrates cross section at the Duc My Bridge.

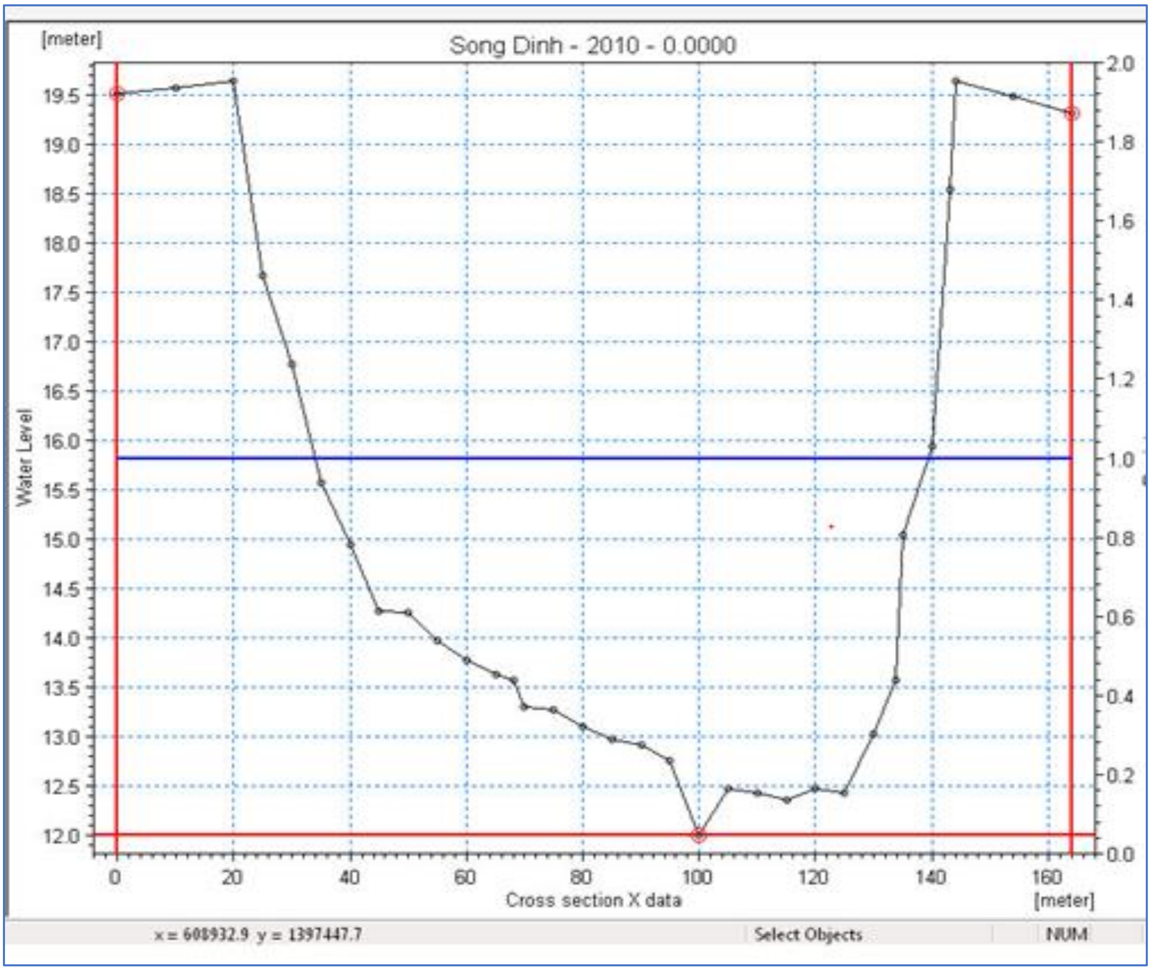

Figure 4. Cross section at the Duc My bridge belong to the Cai river (Dinh River).

Upstream boundary

Due to the lack of flow measurement stations upstream of the river, in 2010, the Hydrometeorological Station of the South Central region measured the flow of the big flood in November 2010 at 4 locations on the Cai rivers, Ninh Hoa River, Tan Binh river, and Dong Nai river. Lam, Lot, Cau Lam River, and three water level points at Ninh Xuan, Ninh Hoa, and Cua Dinh. The boundary of the hydraulic model is the flow process line Q ~ t at: The Ea Krong Rou Reservoir upstream of Dinh River, 2 km above the confluence between Dinh River and Reservoir Ea Krong Rou in Ninh Tay Commune, Ninh Hoa; After overflowing Da Ban reservoir, Ninh Son commune, Ninh Hoa town; In Tan Lam village, Ninh Thuong commune, Ninh Hoa town; In Ninh Tan commune, Ninh Hoa town on Cau Lam river; In Ninh An commune, Ninh Hoa town.

Downstream boundary

Because this area has no tidal level, we calculate the tidal transmission from Phu Quy station to Cai Ninh Hoa estuary for the cases and calculation options so the downstream boundary of tidal water level at Cai River mouth in Ninh Hoa. The Southern Central Coast Meteorological Station carried out the results of these correlation calculations in the Dinh - Ninh Hoa and Cai River inundation mapping project.

Hydrological

In the Dinh River basin, several hydrological stations monitor the flow, yet many of them have ceased measurements, and there is a need for synchronization in the monitoring periods. On the mainstream of the Dinh River, there is no flow measurement data; only Ninh Hoa hydrological station measures the water level. Da Ban hydrological station in the basin has flow measurement data from 1976 to 1981. Therefore, the thesis uses Da Ban hydrological station data to correct the MIKE-NAM flow rain model. The floods that occurred in November 1978 were chosen for model calibration, while the flood in October 1980 was selected for model testing.

Hydrodynamic parameters

The hydrodynamic parameters include the initial conditions of water depth and discharge, friction coefficient, and output parameter options. The present study includes the specification of the global and local values of the riverbed's roughness coefficient (Manning's n), which was the main and only calibration parameter. Other parameters were kept at their default values. The global value for the initial condition of water depth was kept at a low value of 0.01 m to avoid dry bed conditions.

2.2 Method*s*

In the study, MIKE model set is used for calculation, in which: MIKE-NAM model is used to calculate flow in sub-basins as input to MIKE-11 hydraulic model and as input boundary for MIKE-21 FM/3 Couple model; MIKE-21 model is used to calculate input boundaries for MIKE-11 model and MIKE 21FM/3 Couple model; MIKE-21 FM/3 Couple model is used to calculate the hydrodynamic regime in the Duc My area and other river sections. The MIKE-11 and MIKE-21 models simulate unidirectional flow over complex river networks and bidirectional flow over field surfaces. MIKE-11 has limitations in simulating inundation after dam failure; it is difficult to simulate overflow if the reservoir and flow direction are not known in advance and do not describe the basin's velocity. As for MIKE-21, it is limited when you want to study the mainstream flow in the channel; it is necessary to reduce the computational network to the extent that it can represent the topographic change in the channel, which as a result, takes a long time for computation.

The models are used for simulating, taking into account different scenarios with flooded periods such as MIKE-FLOOD, MIKE-11 HD, MIKE-21 FM. The ArcGIS 10.1 software suite is used to present the Duc My bridge flood calculation results on the base map.

MIKE 11

It is a software package for simulating flows, water quality, and sediment transport in estuaries, rivers, irrigation channels, and other water bodies [3,4]. This system has been successfully applied to many regions worldwide, and extensively used by the engineering industry and numerous hydrological consulting groups. The fundamental equations of the MIKE 11 1D model are based on the continuity principle (Conservation of Mass) and momentum principle (Newton's Second Law), as described in Eq. 1 and 2, respectively:

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

$$\alpha \frac{\partial Q}{\partial x} + \frac{\partial}{\partial x}\left(\beta \frac{Q^2}{A} \right) + gA\frac{\partial h}{\partial x} + g\frac{Q|Q|}{C^2 RA} = 0 \qquad (2)$$

where:

Q: flow rate through wet cross-sectional area A (m^3/s)

X: spatial variable (longitudinal distance in the direction of flow) (m)

t: calculation time variable (seconds)

q: additional discharge along the route (perpendicular to the river axis) (lateral inflow) (m^2/s)

A: wet cross-sectional area (m^2)

h: water level above the reference surface (m)

C: Chezy coefficient (Chezy's resistance coefficient)

R: hydraulic radius (m)

α: Kinetic energy correction factor

β: Momentum correction coefficient (momentum distribution coefficient)

g: acceleration due to gravity (9.81 m/s^2)

Eq. (1) and (2) are transformed into a set of implicit finite difference equations and solved using a double-sweep algorithm (Abbot and Ionescu, 1967). The computational grid consists of alternating Q and h points, automatically generated by the model according to user specifications. Q points are always placed midway between neighboring h points. h points are located at cross sections or equidistant intervals in between if the distance between cross sections is greater than the maximum space interval, dx, specified by the users.

The MIKE-11 HD setup requires specification of five fundamental input parameters: river network layout, cross sections, boundary conditions, hydrodynamic parameters, and simulation parameters.

Simulation parameters

Before running the model simulation, control parameters such as simulation period, simulation time step, data to be stored, and storage time were specified. There exists a versatile relationship between the time step and the computational distance to define the Courant number given below in Eq. (3), which is widely considered to choose the time step for the model simulation. Courant number:

$$(CR) = \frac{\Delta t(V + \sqrt{gy})}{\Delta x} \qquad (3)$$

where Δt: time step, V: mean flow velocity (m/s), y: water level (m), and Δx = dx - max. In this study, the time step and computational distance were maintained at 30 seconds and 1000 m, respectively.

Calibration and validation criteria for MIKE-11

The calibration parameter considered for the MIKE-11 HD model was the roughness coefficient of the riverbed (Manning's n). Two goodness-of-fit criteria, Nash-Sutcliffe coefficient (modeling efficiency, ENS) and index of agreement (d), as represented by the following Eq.(4), were used to verify the acceptability of MIKE-11 results.

$$E_{NS} = 1.0 - \frac{\sum (Q_0 - Q_S)^2}{\sum (Q_0 - Q_{av})^2}$$
$$d = 1.0 - \frac{\sum (Q_0 - Q_S)^2}{\sum \left(|Q_0 - Q_{av}| + |Q_s - Q_{av}| \right)^2} \qquad (4)$$

Where, E_{NS} modelling efficiency, Qo: observed value, Qs: simulated value, Qav: mean of the observed values and d: index of agreement.

Two-dimensional MIKE-21 HD model setup

MIKE-21 model has many input parameters, but bathymetry or terrain elevation (Digital Elevation Model in MIKEcompatible format) is the most important input parameter, which contains information regarding the elevations of the flood plain. The Digital Elevation Model, obtained from SRTM-DEM [13] for the study area containing and surrounding the MIKE-11 river network was processed to obtain bathymetry as input for MIKE-21. The resolution of the input bathymetry was 85m×85m, so the computational distance was 85 m, and the time step adopted was 5 seconds for different simulations.

MIKE-FLOOD model setup

The MIKE-11 river network was connected to the MIKE-21 bathymetry using the lateral link option available in the MIKE-FLOOD. Using a cell-by-cell approach, the river bank was dynamically linked with the MIKE-21 grids. Whenever overtopping occurs from the MIKE-11, the MIKE-21 calculates the discharge over each cell using the weir formula. The inundation extent and depth in the flood plain for the overtopping water is calculated by MIKE-21. Other parameters for the left and right bank lateral links, such as momentum factor, weir coefficient, and depth tolerance factor, are kept at their default values. Manning's n at all the link points was also kept at the default value of 0.043. MIKE-FLOOD is set up along with the river, and both the lateral links are shown in Fig 3.

The gauge and discharge data at two monitoring stations on river Dinh (downstream) maintained by Hydrometeorological Data and Information Center were recorded for use in MIKE-11. The discharge data at Ninh Hoa station were used as the upstream boundary and water level data for calibration and validation of MIKE-11.

MIKE-FLOOD dynamically links two independent software packages: MIKE 11 (1D) and MIKE-21 (2D). In which MIKE-11 solves the Saint-Venant equations through a finite difference scheme. Breaches can be modeled employing a "dam break" structure. Breach growth can be described by time series for breach width, crest level, and side slope. Fig 7 describes the application of lateral links in MIKE-FLOOD. Applications of MIKE-FLOOD to simulate the inundation at downstream areas have been applied in previous studies.

3 RESULTS AND DISCUSSION

For simulating flood inundation extent by MIKE-FLOOD, a stable, calibrated, and validated 1D flow, MIKE-11 models must be linked to the 2D flow model MIKE-21. The MIKE-11 model was calibrated using the discharge- and water-level data that was available for the Ninh Hoa station observed for the four flood events of years 11/2009 and 11/2010 and validated for two flood events of years 11/2017, and 11/2018. These events were selected after a thorough data search, and they were allotted arbitrarily for calibration and validation. Subsequently, MIKE-FLOOD was simulated using the calibrated setup of MIKE-11 for the flood event between 07 to 16 November for the year 2019. In the simulated flood with the time of occurrence of the flood peak, the correlation coefficient is high, and the indicator (Nash–Sutcliffe) is over 0.75.

Calibration of MIKE-11

The only parameter used in MIKE-11 for the calibration was Manning's roughness coefficient, n. In the hydrodynamic parameters for MIKE-11, Manning's n is specified as Global and Local values. The roughness coefficient was adjusted in calibration to obtain the least possible gap between the observed and simulated water depths. The simulated water depth at the Ninh Hoa station was compared with the corresponding observed values. By changing the global roughness coefficient and fixing the local roughness coefficient at 0.00 km chainage of the river as constant, the setup was simulated, and the results were compared with the observed values. Further, the local roughness coefficient for the river was varied from 0.00 km chainage, and fixing the global value of the roughness coefficient, the setup was executed for calibration. The final value of the global roughness coefficient was found to be 0.033, where the local values ranged from 0.0233 to 0.045 for the four calibration events at 0.00 km chainage. Table 2 presents the calibrated values of Manning's roughness coefficient, n.

Table 2. Calibration values of Manning's roughness coefficient, n for MIKE-11.

		Manning's roughness coefficient n ($m^{-1/3}$ s)	
No.	Name of river	Local (chainage 0,00 km)	Global
1	Dinh	0.043	0.033
2	Tan Lam	0.043	
3	Da Ban	0.045	
4	Cau Lam	0.043	

Validation of MIKE-11

Because of the unavailability of water level and discharge data from gauging stations so data from Ninh Hoa station were used to validate the model, and the data for the monsoon period of 2009 and 2019 (Fig 5 and 6) were used to calibrate the MIKE model.

For the event of 2009, the goodness-of-fit criteria was seen to be good and the peak observed and simulated water levels were also in close agreement along with their timings.

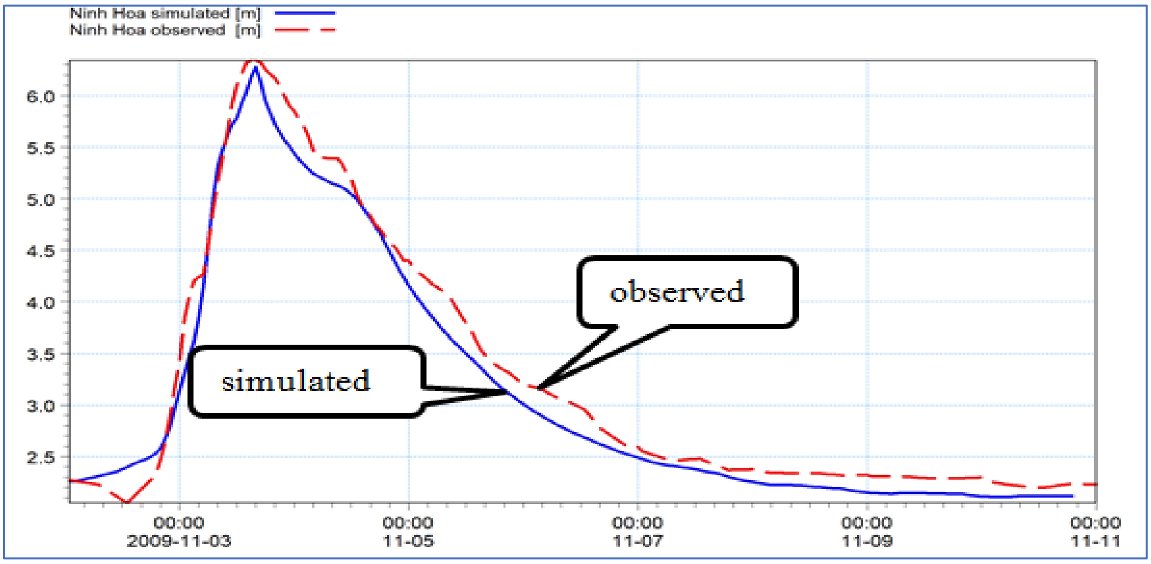

Figure 5. Comparison of observed and simulated water levels at Ninh Hoa gauging site (1/11/2009 to 10/11/2009) for calibration event.

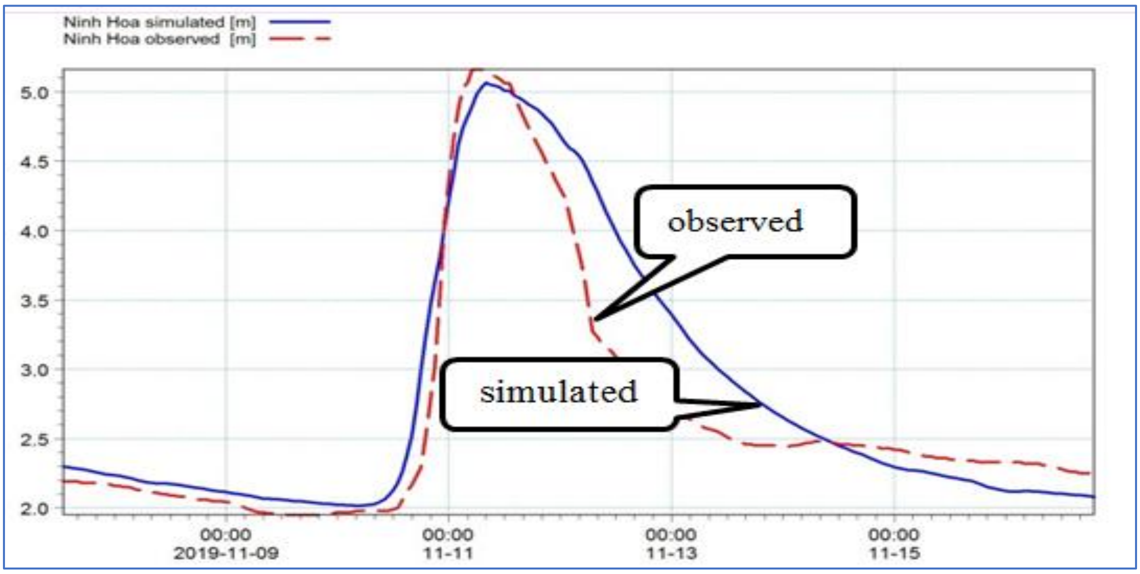

Figure 6. Comparison of observed and simulated water levels at Ninh Hoa gauging site (7/11/2019 to 16/11/2019) validation event.

In fact, the coefficient of determination (R^2) for the plot between simulated and observed peak water levels for 2009 is very encouraging. The times to peak for the data of the calibration data of 2009 and validation data of 2019 show a lag of about a couple of hours in each case.

Dynamic simulation of flood inundation using MIKE-FLOOD

The single flood event of the year 2019 in the Dinh River flood plain was simulated using MIKE-FLOOD, which integrated the calibrated and validated 1D MIKE-11 hydrodynamic model with 2D hydrodynamic model MIKE 21 for the floodplain. MIKE-FLOOD was simulated for two monsoon months of 2019, from 07 November to 16 November. The initiation of the flooding was visualized with the help of the Result Viewer tool, and the subsequent extent of flooding was captured at arbitrarily chosen instants of time. The flood inundation extent selected, namely 16 November, is shown in Fig 7-9, respectively. It is observed from the simulated results that the flooding in the Dinh River floodplain first starts near the confluence of its tributary Ninh Hoa (at chainage 8 km measured from the Duc My road bridge) as the floodplain is instead very flat at this location. Flood water is also overtopping from the left bank and travels downstream, including an extensive and shallow channel through the flood plain almost parallel to the river (Fig. 7). Flooding downstream of the Dinh River floodplain is seen to occur due to the overtopping and continuous flow of flood water from the upstream floodplain through wide and shallow channels (Fig. 8 and 9).

Scenario 1C corresponds to the scenario governed by regulations for coordinating reservoir operations during the annual flood season.

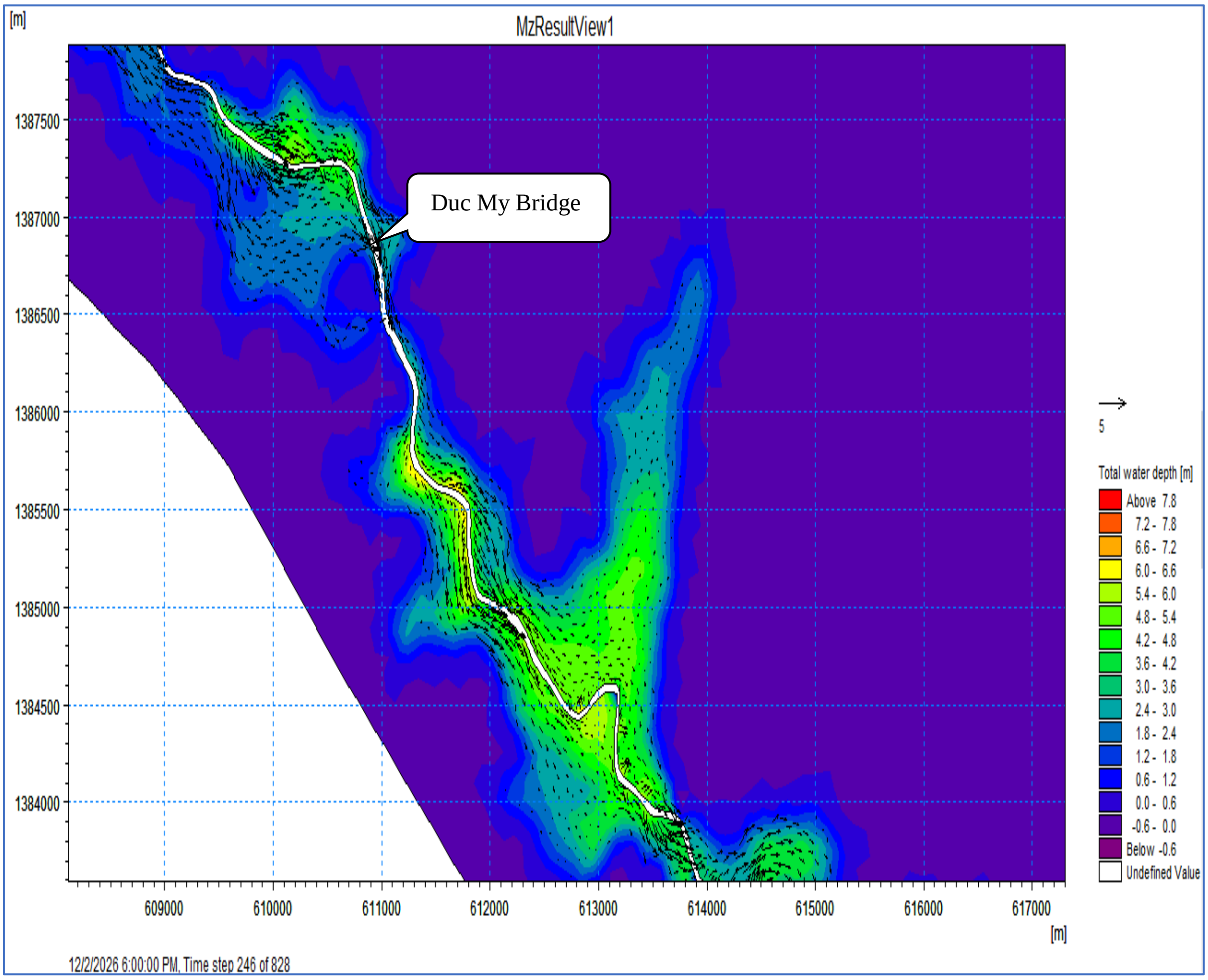

Figure 7. Flood inundation extent as on 16 November 2019, SC 1C.

Fig. 7 shows the innundation map due to the 2016 flood in the Cai River system. The maximum inundation level is 4m; the Duc My bridge area's largest flood level is 2m.

Scenario 2C is the case that the Da Ban Reservoir, Eakrong Rou Reservoir, and Suoi Trau Reservoir operate according to regulations. A dam failure occurred at Ea Krong Rou Reservoir.

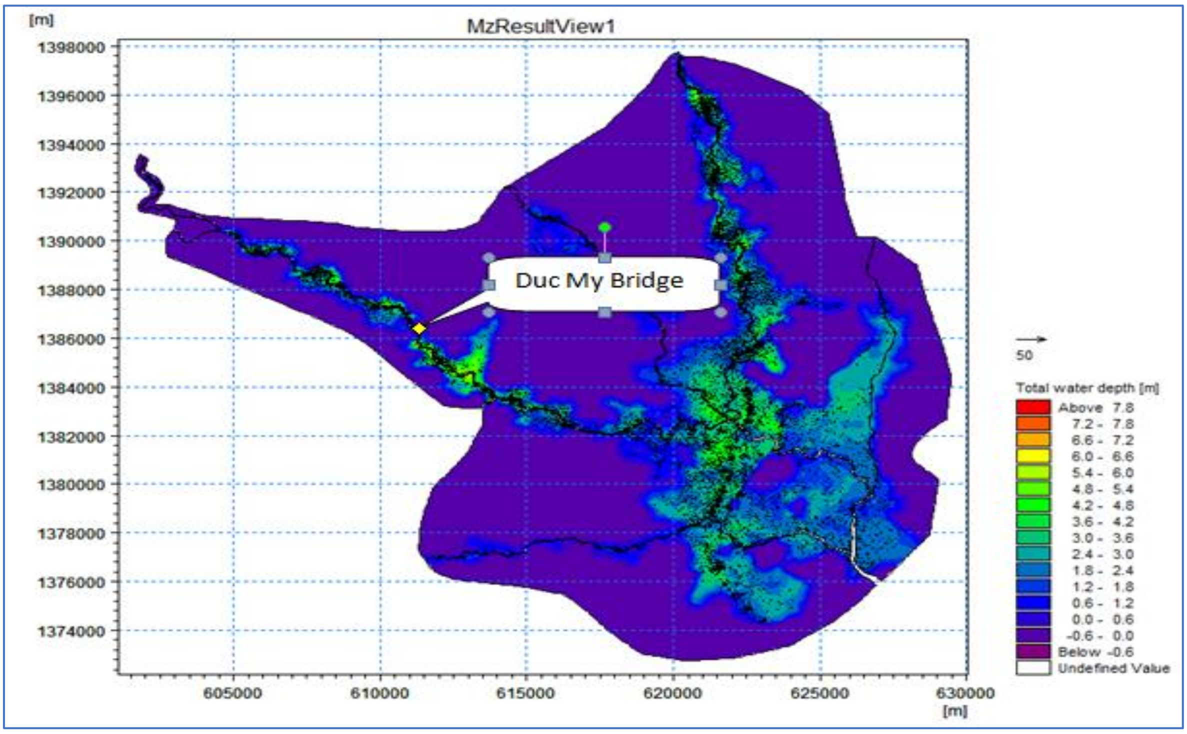

Figure 8. Flood inundation extent as on 16 November 2019, SC 2C.

Scenario 3C is the case of dam failure occurring at all three reservoirs, Da Ban Reservoir, Eakrong Rou Reservoir, and Suoi Trau Reservoir.

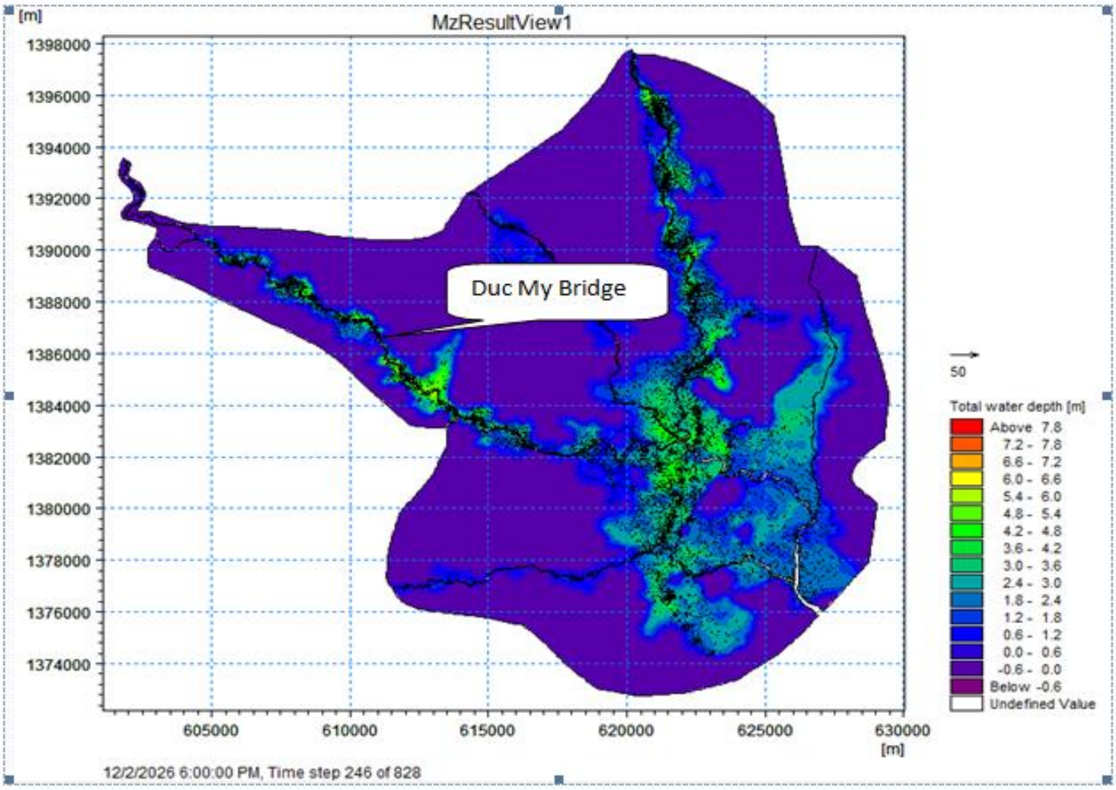

Figure 9. Flood inundation extent as on 16 November 2019, SC 3C.

The area inundated, as observed in the Dinh River flood plain for the year 2019, was found to be 15116,20 ha. Whereas the area inundated, as calculated from MIKE-FLOOD simulation for two effective monsoon months of the year 2019, was found to be 15872,77 ha. The simulation's inundation depth was 0 to 3 m, excluding some extreme values.

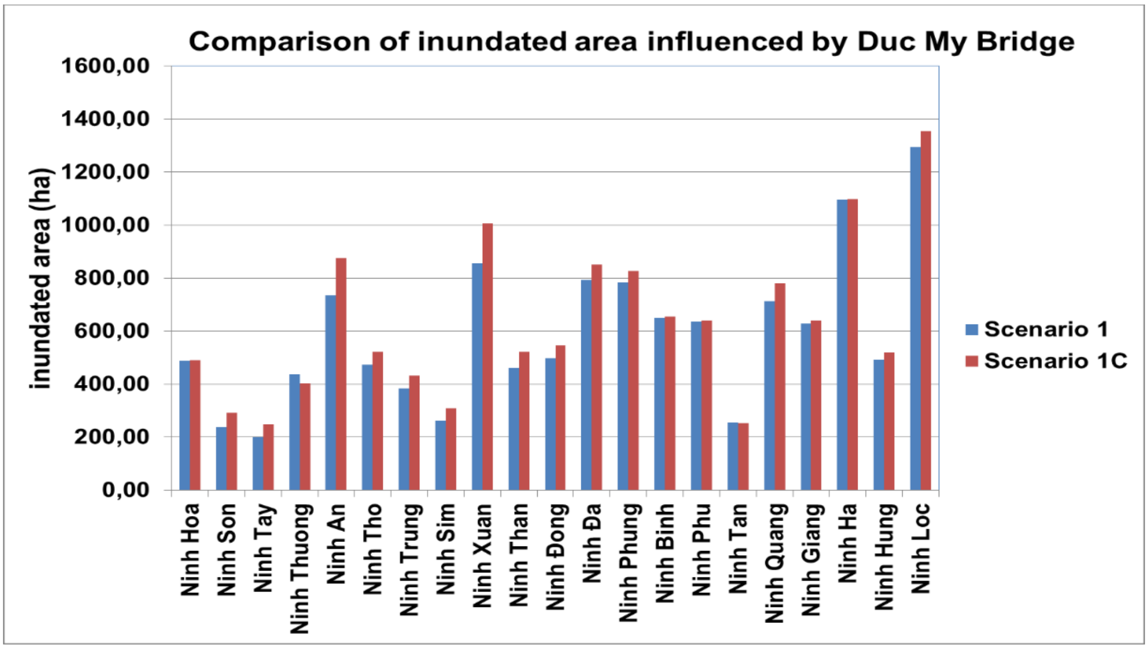

Figure 10. Comparison of flooded areas in scenarios 1 and 1C.

Fig. 10 shows the area flooded for Scenario 1(without the participation of the Duc My Bridge) and 1C (with the involvement of the Duc My Bridge). In most locations, the measured inundation level in scenario 1C is greater than 1. At this time, the reservoirs discharge flood according to regulations on coordination of operation of reservoirs in the annual flood season.

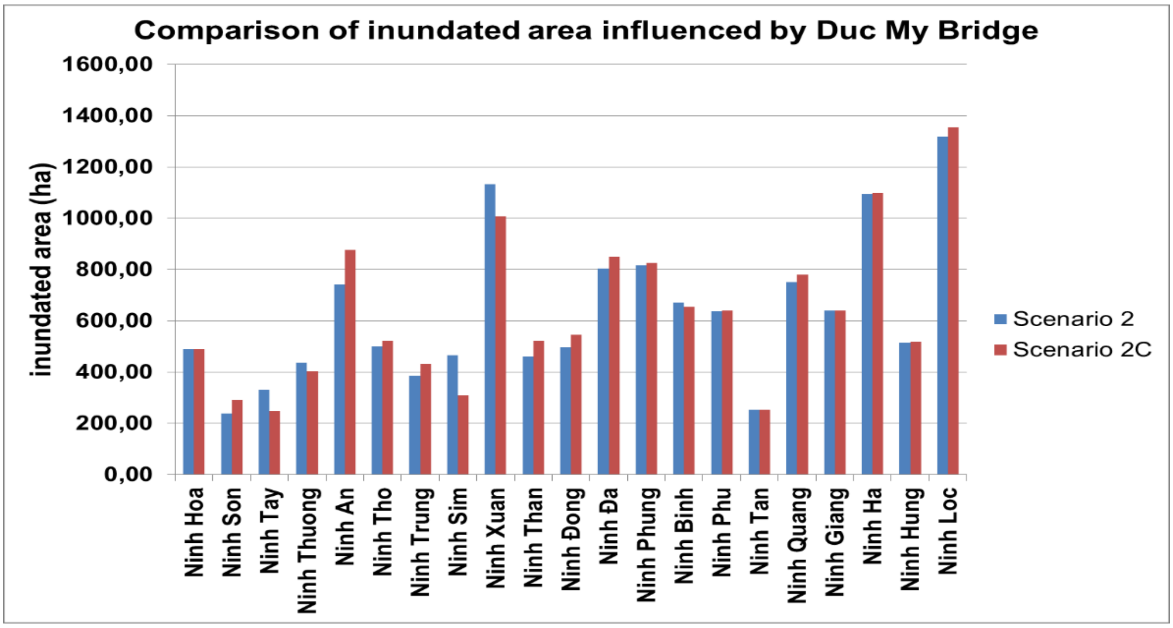

Figure 11. Comparison of flooded areas in scenarios 2 and 2C.

Fig. 11 shows the area of flooding for Scenario 2 (without the participation of the Duc My Bridge) and 2C (with the involvement of the Duc My bridge). In numerous locations, the recorded inundation level in Scenario 2C surpasses the value of 2. At this time, the reservoirs of Da Ban Reservoir, Eakrong Rou Reservoir, and Suoi Trau Reservoir operate according to regulations. A dam failure occurred at Ea Krong Rou Reservoir.

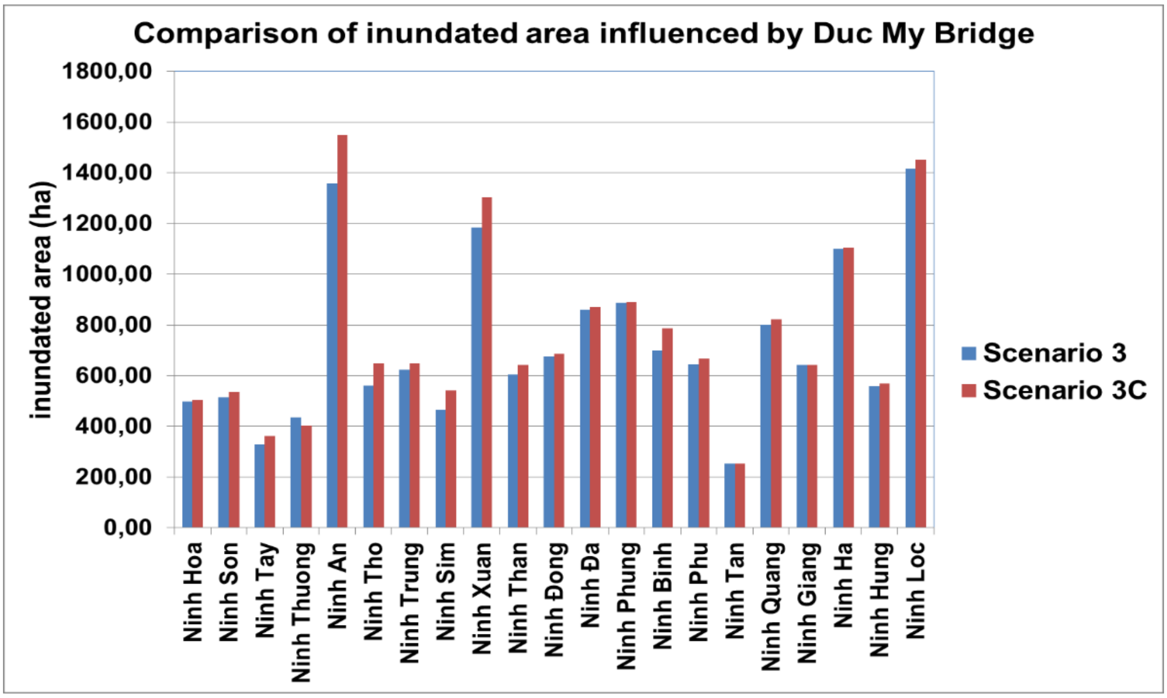

Figure 12. Comparison of flooded areas in scenarios 3 and 3C.

Fig. 12 shows that dam failure occurs at all three reservoirs, Da Ban Reservoir, Eakring Rou Reservoir, and Tuoi Trau Reservoir to the highest inundation (scenarios 3 and 3C).

As can be seen, Fig. 10 to 12 are a comparison chart of flooding levels in 21 different communes in the study area under different reservoir operation scenarios (without the participation of and with the involvement of the Duc My Bridge).

In all three graphs, with scenario 3 (all three reservoirs failed), the damage and inundation downstream are considerable, especially with the bridge's involvement, which increases the inundated area downstream than other scenarios.

Especially in the Duc My bridge area (in Ninh Sim commune), the inundated region increased by 203,273 hectares (an increase of 77.25%) in scenario 1 (regularly operated reservoir) compared to scenario 3 (all three reservoirs are damaged and without bridge). Meanwhile, the flooded area increased by 231,218 hectares (an increase of 74.82%) in scenarios 1C (regular operation of the reservoir, with the participation of Duc My bridge) compared to scenario 3C (failure of all three reservoirs, with the involvement of Duc My Bridge), as shown in Figure 13.

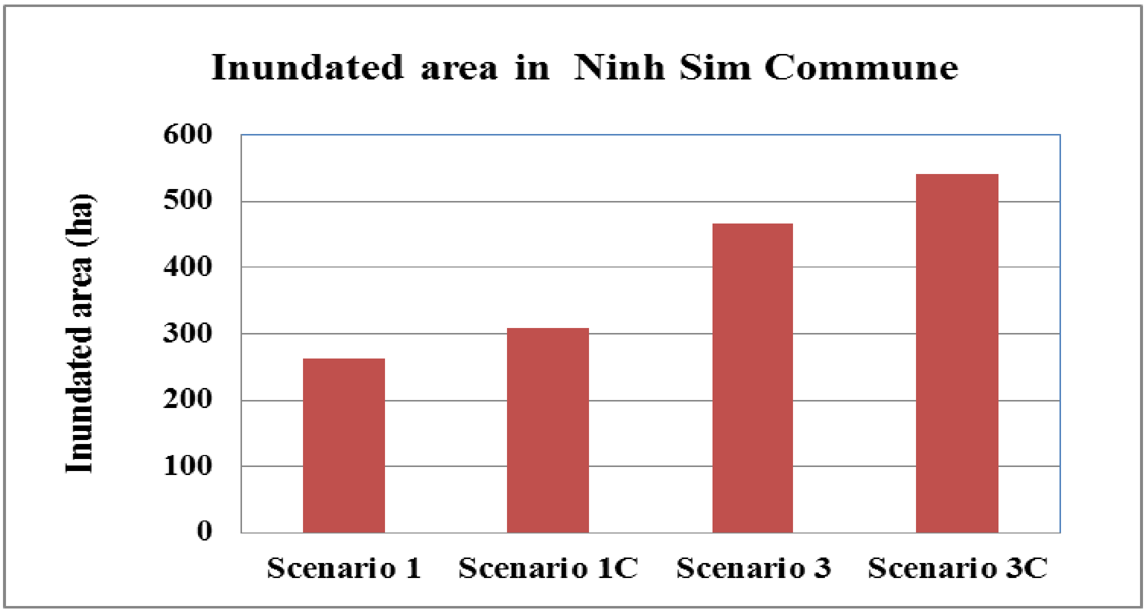

Figure 13. Inundated areas in scenarios 1, 1C, 3, and 3C.

4. CONCLUSION

This article set up MIKE-11 hydrodynamic model to calculate the dam break and simulate its propagation along the Dinh River to investigate the impacts of the failure of the Ea Krong Rou reservoir and reservoir systems on the area downstream of the dam.

Manning's roughness coefficient was determined to be 0.043 as the optimal global value for the hydrodynamic parameters of the MIKE-11 model, yielding the most accurate simulation results for the Dinh River.

In the Duc My Bridge area, Ninh Sim commune, the inundated area increases with the participation of the bridge. Especially the 3C scenario (Most unfavorable) has the most significant flood level compared to the other scenarios (Scenario 1, 1C, 2, 2C, 3).

An inundated map in the 3C scenario (When all three reservoirs in the study area failed) with a large floodplain area and high flood level leads to a safety assessment of the bridge, taking into account the problem of the system hydraulics (reservoirs, river systems, and other structures) rather than separately as at present.

The result of this study can be estimated inundation maps for downstream, which are used as the basis for the Emergency Action Plan when a flood occurs.

ACKNOWLEDGMENT

This research is funded by University of Transport and Communications (UTC) under grant number T2023-CT-027.

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