International Journal of GEOMATE, Nov., 2024 Vol.27, Issue 123, pp.38-45
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.123.4617
Geotechnique, Construction Materials and Environment

FLOOD INUNDATION ANALYSIS IN DOWNSTREAM OF SMALL HYDROPOWER PLANT: A CASE STUDY IN LANG SON PROVINCE, VIETNAM

*Ngo Phuong Le[1], Nguyen Binh Khanh[1], Truong Nguyen Tuong An[1], Luong Ngoc Giap[1] and Pham Ngoc Kien[2]

[1] Institute of Science and Technology for Energy and Environment, Vietnam Academy of Science and Technology, Hanoi, Vietnam; [2] Electric Power University, Hanoi, Vietnam

*Corresponding Author, Received: 04 July 2024, Revised: 01 Oct. 2024, Accepted: 09 Oct. 2024

ABSTRACT: Hydropower is well known as one of the most economical traditional energy sources, and it is clean and renewable in the world so far. This resource has been harnessed for socio-economic development and energy security in Vietnam. Small hydropower projects have contributed significant power to the national power grid thanks to their economic investment and environmental friendliness. However, the small hydropower was restrictive on flood regulations and risked potential incidents such as dam breaks during operation. Therefore, it is necessary to study the risk of downstream inundation due to flood discharge or dam break. This study uses HEC-RAS software to map flood inundation applied downstream of Thac Xang hydropower (Lang Son, Vietnam) at three (03) active flood discharge scenarios and two (02) dam break scenarios. The results show that the hydropower reservoir can help reduce flood peaks by 6.54% for a flood frequency of 1% but does not help reduce flood peaks in the case of flood frequency of 0.2% and 0.1%. In addition, the flood peak time is also delayed from 1.0 to 1.8 hours. The inundation map results show that in the event of a dam break during flood discharge, the flooded area will increase by 9.89%, the flooded residential area will increase by 12.47%, and the flooded depth will increase by 13.08%.

Keywords: HEC-RAS Simulation, Inundation Analysis, Dam Break, Small Hydropower

1. INTRODUCTION

Hydropower has been well known as the cheapest traditional energy source, which was clean and renewable in the world [1,2]. Thanks to its great potential, this resource has been harnessed for socio-economic development and energy security in Vietnam [3]. Investment in the construction of small hydropower projects (installed capacity <30 MW [4]) in recent times has contributed a significant electricity output to the national power grid, taking advantage of this valuable renewable energy source. Small hydropower is recognized as one of the most economical and environmentally friendly power sources [5]. The period of strong development of small hydropower started from 2008 - 2009 and lasted until 2016. Until 2017, Vietnam has put into operation 190 small hydropower projects and another 180 under constructions, with a total installed capacity of 3.8 GW [4].

Nevertheless, in term of flood control, small hydropower is relatively limited because its less protective standard comparing the regular hydropower dam. Therefore, analysis of downstream flooding risks caused by small hydropower flood discharges and/or dam break is required.

Dam break analysis can be studied in the form of small-scale physical models to study flood transmission [6] or by dam break simulation software such as HEC-RAS, FLDWAF and DAMBREAK, MIKE FLOOD. Comparison between the computational softwares shows equivalent results for similar dam break parameters, cross-sectional properties, boundary conditions [7].

Several studies on flood inundation analysis due to flood discharge and dam breach using HEC-RAS have also been conducted by [8–13]. This model is suitable for overtopping as well as pipe breaking in both earthfill and concrete dams. The resulting downstream flood waves are routed using unsteady flow equations [14].

In this paper, we will simulate models of reservoir, dam, river, and flow area, then export an inundation map for the downstream of Thac Xang hydropower plant (on Bac Giang River, Hung Viet commune, Trang Dinh district, Lang Son province) and calculate some main parameters, such as peak flow (in and out), inundation area, depth, inundation residental area, etc. Three (03) scenarios of active flood discharge with different flood frequencies and two (02) dam break scenarios will be studied and simulated using HEC-RAS 6.4.1. The simulation results can be used to identify risk areas and provide early warning to minimize the impact of floods in the Thac Xang hydropower downstream, focusing on That Khe town area, a densely populated area.

The paper content is consisted of six sections: introduction, research significance, data and methodology, results and discussions, conclusions and references.

2. RESEARCH SIGNIFICANCE

In this paper, HEC-RAS 6.4.1 was used to simulate three (03) scenarios of active flood discharge with different flood frequencies and two (02) dam break scenarios of Thac Xang hydropower plant. The simulation results can help identify high-risk areas and offer early warnings to reduce the impact of floods in the downstream region of Thac Xang hydropower, with particular attention to the densely populated That Khe town.

3. DATA AND METHODOLOGY

3.1. Study Area

Thac Xang Hydropower Project is built on Bac Giang River, a level 1 tributary on the left bank of Ky Cung river. The project is located in Hung Viet commune, Trang Dinh district, Lang Son province, more than 3km from the junction of Bac Giang and Ky Cung rivers, about 10km from That Khe town by straight line to the south, about 60km from Lang Son city to the northwest. The project location has the following geographical coordinates: 22º09'40" North latitude - 106º29'30" East longitude. The river network, river basin area and Thac Xang dam location were presented in Fig. 1. That Khe town, where the flood risk analysis must be focus on, is also shown on Fig. 1. Some main parameters of Thac Xang Hydropower Project are shown in Table 1.

Table 1. Main parameters of Thac Xang hydropower

No.	Parameter	Value
1	Basin Area	2660 km²
2	Normal Water Level	183 m
3	Dead Water Level	182 m
4	Total Capacity	43.89 million m³
5	Useful Capacity	3.96 million m³
6	Number of Spillway Chambers	3
7	Size of Spillway Chambers	14.5 x 16 m
8	Installed Capacity	20 MW
9	Average Annual Power	74 million kWh
10	Design Discharge (exceedance probability 1%)	
	Upstream Water Level	183m
	Downstream Water Level	167.13 m
11	Exceptional Discharge (exceedance probability 0.2%)	
	Upstream Water Level	185.07 m
	Downstream Water Level	169.94 m

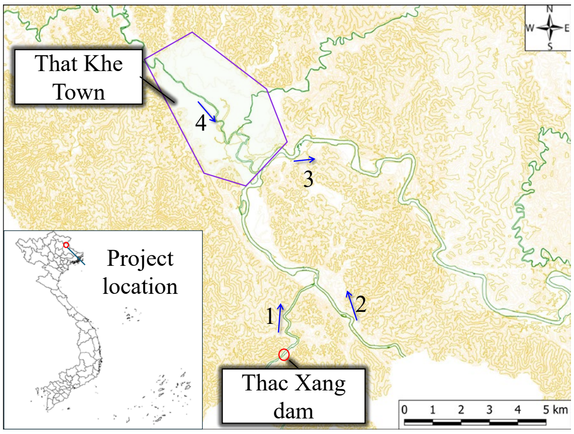

Fig. 1. River network, river basin area and Thac Xang dam's location (1-Bac Giang river, 2,3 - Ky Cung river (upstream), 3-Ky Cung river (downstream), 4-Bac Khe river)

3.2. General Methodology

The flood analysis method is performed based on HEC-RAS software. HEC-RAS flood analysis software is a powerful tool developed by the US Army for modelling the flow in rivers and channels [15].

The HEC-RAS system includes the following river analysis components for: (1) one-dimensional steady-flow water surface calculations; (2) one-dimensional and/or two-dimensional unsteady-flow simulations; (3) fully or nearly unsteady-flow boundary sediment transport calculations (1D and 2D); and (4) one-dimensional water quality analysis [16].

The method of performing flood and dam break analysis includes the following steps:

- Step 1: Collect input data: hydrology, topography, reservoir parameters, hydropower dams, spillways, etc.
- Step 2: Build geometric models:
  - Build 1D geometric model of the river/channel, including cross-sections of the river.
  - Build 2D geometric model, which is suitable for large flood areas where the flow can be distributed more freely.
  - Link 1D and 2D models through lateral structures to connect the river along the floodplain, or inline structures to connect the river horizontally to the reservoir or floodplain.
  - Enter model specifications: manning coefficients, dam parameters, etc.
- Step 3: Set boundary and initial conditions:
  - Boundary conditions: Define the inlet and outlet flows for the model, based on hydrological data or forecasts.
  - Initial conditions: Set the initial water levels in the river/channel and inundation areas.

- Build a dam breach scenario: define breach characteristics (height, width, time to develop breach, etc.)

• Step 4: Simulation: Use HEC-RAS to run the simulation, allowing the flow to move freely between 1D and 2D regions based on the boundary conditions and established connections.

• Step 5: Analyze results: Review the simulation results to understand the water levels, flow rates, and inundation areas throughout the model area.

• Step 6: Model validation and calibration: test the model using data from different flood events to ensure that the model performs well in a variety of scenarios. Adjust the model parameters based on comparing the simulation results with actual data to achieve higher accuracy.

• Step 7: Evaluation and use of results: Use the results to identify areas at high risk of flooding and the severity of flooding. Apply the results to flood prevention planning, construction of protective structures, and evacuation planning when necessary.

3.3. Input Data

Data used for flood analysis include hydrological data, topography, reservoirs, hydropower dams, gates, residental areas, population, downstream affected areas, etc.

In terms of hydrology, this simulation uses inflows based on the hydrograph discharge as shown in Fig. 2. Hydrological data were taken from previous studies using the flood peak module reduction method from the Van Mich hydrological station according to the data series 1960-2008, including the historical floods in 1986 and 1992. According to actual flood flow measurements of the Van Mich hydrological station from 1960-1976, it shows that in a flood season, about 3-4 floods usually appear. The duration of a flood usually fluctuates between 1-5 days. From the flood data extracted from the Van Mich station during the period 1960-1976, representative floods were selected, namely the floods of 1966; 1968 and 1971 with large peaks and flood volumes as typical floods to zoom in on the design flood process.

The topography provided for this simulation is taken from the 1:10000 scale map data of Trang Dinh district, provided by the Department of Surveying, Mapping and Geographic Information of Vietnam. The data is in vector format, saved in DWG format of AutoCAD. To be able to import the data into HEC-RAS software, the above data is converted to Digital Elevation Model (DEM) data with a resolution of 10 meter using the GRASS toolkit in QGIS software.

Other data, such as reservoir characteristic curve, parameters of hydropower dam and gates, boundary conditions of upstream and downstream of rivers, boundary conditions of reservoir, initial conditions, simulation scenerios, dam break parameters, will be presented more detail in the next sections.

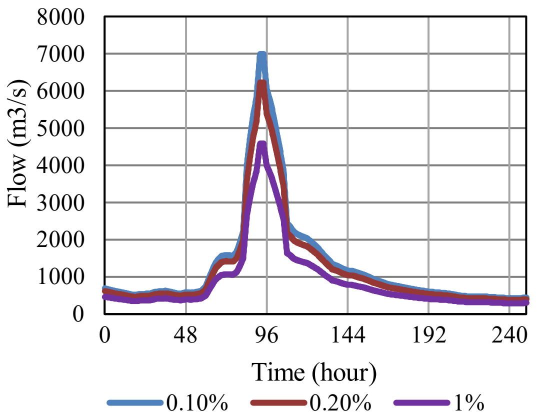

Fig. 2. Hydrograph discharge with probability of 0.1%, 0.2% and 1%

3.4. Geometric Model

The geometric model constructed is shown in Fig. 3, including the following main components:

- Hydropower reservoir (as storage area) and hydropower dam (as inline structure), which was presented in more detail in Fig. 4.
- Rivers including Bac Giang River and Ky Cung River, river cross-sections, riverbanks.
- That Khe Town as a 2D flow area.

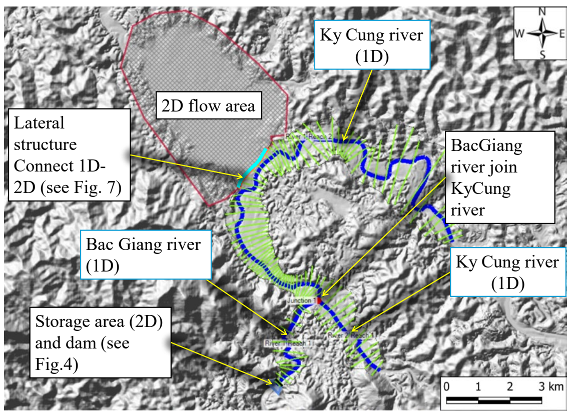

Fig. 3. Overall geometric model of the simulation.

The hydropower reservoir is just defined symbolically in terms of geometry (Fig. 4), however, is defined accurately in terms of volume-water level relationship (Fig. 5).

The river model is a 1D hydraulic model, in which the Bac Giang River starts from the reservoir of Thac Xang hydropower dam (Fig. 4). The upstream part of the Bac Giang River outside of the Thac Xang hydropower reservoir is not considered. There is one river cross section located in the reservoir model (cross section 1 in Fig. 4) and one river cross section located outside the reservoir model (cross section 2 in Fig. 4), the closest distance between them can be from 3~6m [16].

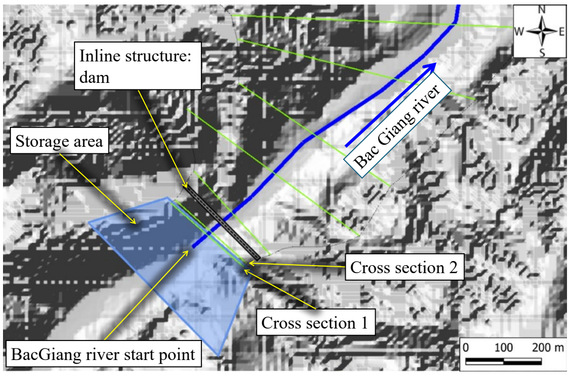

Fig. 4. Model of Thac Xang hydropower dam and reservoir

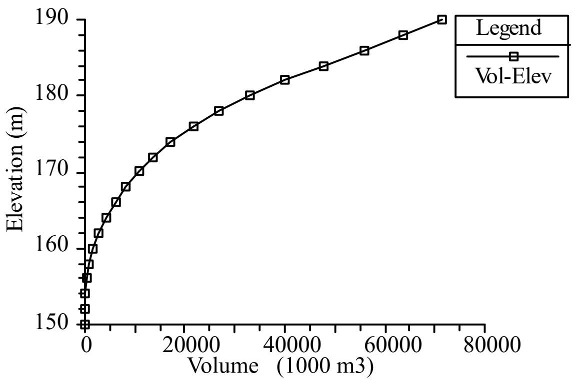

Fig. 5. Reservoir characteristic curve (volume-water elevation)

Following cross section 2 is the hydropower dam which is defined as an inline structure. Fig. 6 shows the cross section of the dam with 03 spillways. The spillways with gate are located in the middle of the riverbed of the dam line.

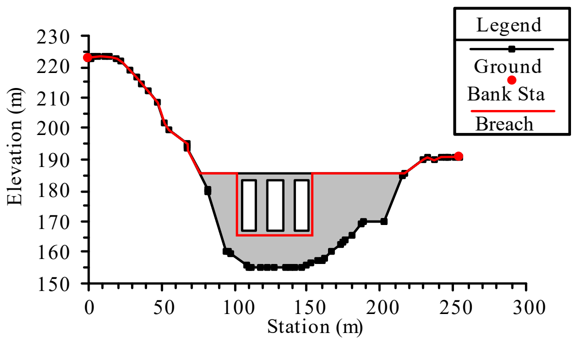

Fig. 6. The dam cross section includes 03 spillways and the largest breach.

In the downstream, Bac Giang River merges with the Ky Cung river at the intersection of 3.6 kilometers from the Thac Xang hydropower dam. The Ky Cung river keep flowing on about 6.1 kilometers the to northwest cross the That Khe town, then flows back to the east. In the scope of study, the Ky Cung River is just geometrically defined for an additional 11 kilometers after That Khe town. The number of river cross-sections on all rivers will be 90 sections, averaging approximately 230m per section.

The main flood area considered in the study is That Khe town, defined as a 2D flow area. This 2D flow area has an area of 19.76 km^2, divided into 195932 cells, with an average size of 10x10m.

The 1D model of Ky Cung river running cross That Khe town is connected to the 2D flow area model by a lateral structure (plan view on Fig. 7, cross section on Fig. 8).

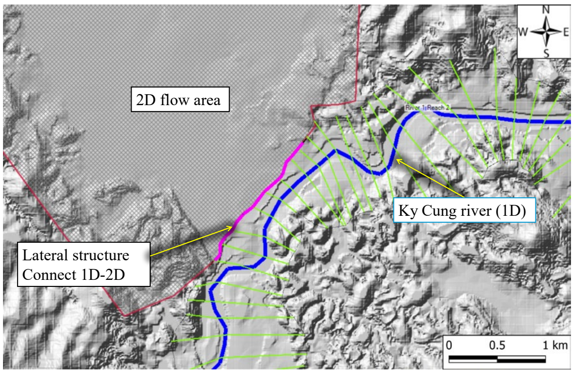

Fig. 7. Plan view of the lateral structure model connecting 1D model of Ky Cung river and 2D flow model of That Khe town

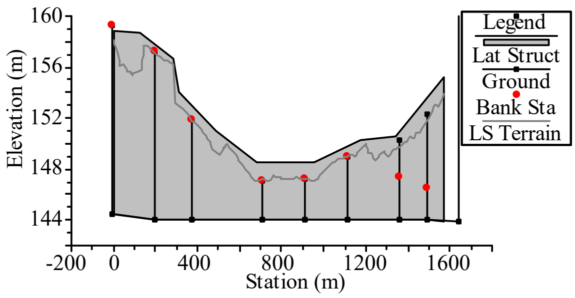

Fig. 8. Cross section of the lateal structure model connecting 1D model of Ky Cung river and 2D flow model of That Khe town.

3.5. Simulating Scenario and Boundary Conditions

Based on Vietnamese technical standard TCKT 03:2015/TCTL [17], the simulation scenarios are:

- P1.1: Active flood discharge with design flood (exceedance probability 1% or 100-year flood)
- P1.2: Active flood discharge with test flood (exceedance probability 0.2% or 500-year flood)
- P1.3: Active flood discharge with exceeding control flood (exceedance probability 0.1% or 1000-year flood)

- P2.1: Dam break in normal (non-rainy) weather conditions, however, encountering a construction incident causing the dam break such as earthquake.
- P2.2: Dam break in rainy and flood conditions, during an active flood discharge with design flood (exceedance probability 1% or 100-year flood).

The flood process is simulated in the software using Unsteady Flow, in which the discharge varies over time as shown in Fig. 2.

The boundary condition of the reservoir is defined by the lateral flow to simulate the flood to the reservoir. This boundary condition is defined in scenarios P1.1, P1.2, P1.3 and P2.2, the value of flood inflow to the reservoir is shown in Fig. 2.

Boundary conditions of Thac Xang Hydropower Dam:

- The opening of the discharge gate is set to the maximum to proactively anticipate the flood in the cases of flood discharge (P1.1, P1.2, P1.3, P2.2) and open 10% in the case of dam break under normal conditions (P2.1).
- Dam break parameters (corresponding to scenarios P2.1 and P2.2): The size of gates breach is based on the design data of the spillway: three (03) gates of three (03) spillways and pillars are broken, the dimension of the breach is 50.5 m x 18.5 m. The breach model is shown in Fig. 6. The breach spreading time of 10 minutes was chosen for calculation.

Boundary conditions of the upstream of Ky Cung river branch is a fixed flow rate of 260 m^3/s.

Boundary conditions of the downstream of Ky Cung river branch is a normal depth with a friction slope is 0.01.

Initial conditions: the initial water level at the reservoir is the designed normal water level, which is 183 meters.

It shall note that the active flood discharge scenarios are prioritizing the safe operation of the plant and minimizing flooding in the downstream area without optimizing the power generation efficiency of the hydropower plant, therefore the spillway is opened to the maximum before the flood peak. In the reality, the hydropower always regulates the reservoir water level to keep maintaining maximize power generation according to reservoir operation process. In this study, the simulation of the reservoir operation process as above has not been considered.

3.6. Model Limitations and Uncertainties

Because the study focuses on analysis of the flood from the upstream of Thac Xang hydropower and its dam break problem, there are limitations of the model as following:

- Precipitation in the whole area is not considered
- Flow from upstream section of Ky Cung River is constant

Some of sources of uncertainty of in the model can be mentioned:

- The input topographic data is taken from the 1:10000 scale map data of Trang Dinh district, which is not a very high resolution data
- The manning's roughness coefficients were based on the guidances in TCVN 13615:2022 (Calculation of Design Hydrological Elements) [18], which requires the future step of validation and calibration.

4. RESULTS AND DISCUSSIONS

4.1. Flood Discharge Process

The flood discharge process at the dam cross-section is shown on Fig. 9. The main parameters of all active flood discharge scenarios (P1.1, P1.2, P1.3) are presented in Table 2.

Comparing the reservoir water level and downstream water level in the flood discharge simulation (Table 2) with the upstream water level and downstream water level in the design parameters of Thac Xang Hydropower Plant (Table 1) shows similar results. The downstream water level in this simulation is approximately 0.14~0.28m lower than the designing level. The upstream water level (reservoir) in the simulation is approximately 0.2~1.8m lower than the designing level.

Fig 9a and Table 2 shows that during the active flood discharge scenarios with design flood (P1.1), the hydropower dam allowed to reduce the flood peak by 6.54% (from 4594 m^3/s to 4294 m^3/s) and delayed the flood peak time by 1.8 hours. In the active flood discharge scenarios with exceptional flood (P1.2) and exceeding control flood (P1.3), the flood peak did not decrease, however, the hydropower dam could be able to delay the flood peak time by 01 hour.

In the case of dam break during an active flood discharge with design flood (P2.2), the discharge flow increases sharply, reaching a peak value of about 6600 m3/s compared to 4294 m3/s in the case of Active flood discharge with design flood (P1.1). In the case of dam break due to earthquake in normal weather conditions (P2.1), the discharge flow increases very high to about more than 9300 m3/s, higher than in case P2.2 because the reservoir is storing water at the normal water level (see Fig 9b).

It should be noted that the active flood discharge scenarios can achieve the above results because the flood gates are fully opened before receiving flood, prioritizing safe operation, and minimizing flooding in the downstream area. This allows to cut back power generation efficiency of the plant during flood discharge.

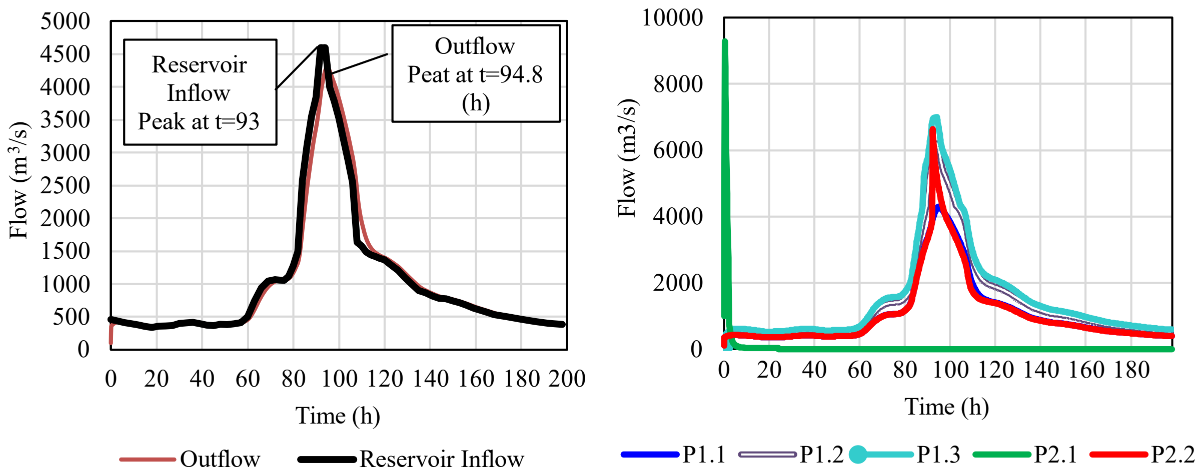

Fig. 9. Flood process at dam cross-section: a) Left: Inflow vs outflow of reservoir in scenerio P1.1; b) Right: Outflow in all scenerios

Table 2. Flood process parameters of of active flood discharge scenarios

Scenerio	Description	Peak inflow (m^3/s)	Peak outflow (m^3/s)	Flood delay (hour)	Upstream WSE (m)	Downstream WSE(m)
P1.1	Active flood discharge with design flood	4594	4294	1.8	182.81	166.85
P1.2	Active flood discharge with exceptional flood	6224	6224	1	183.26	169.8
P1.3	Active flood discharge with exceeding exceptional flood	6993	6993	1	183.42	171.67

4.2. Inundation Map

The inundation boundary map of each simulated scenario is presented in Fig. 10. The inundation map and flooded residential locations (red) corresponding to the most severe flood scenario P1.3 are shown in Fig. 11. The inundation parameters of all the scenarios are shown in Table 3. The last row of the table is the comparison between scenarios P2.2 and P1.1.

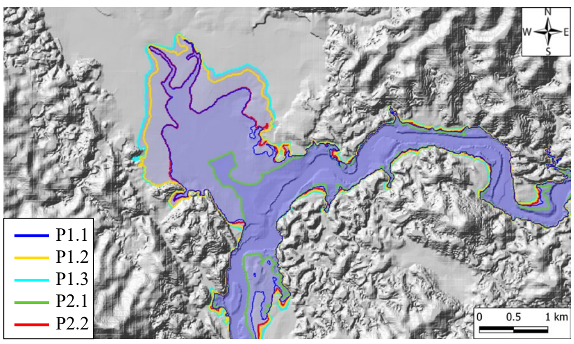

Fig. 10. Inundation boundary map (maximum) for each scenario

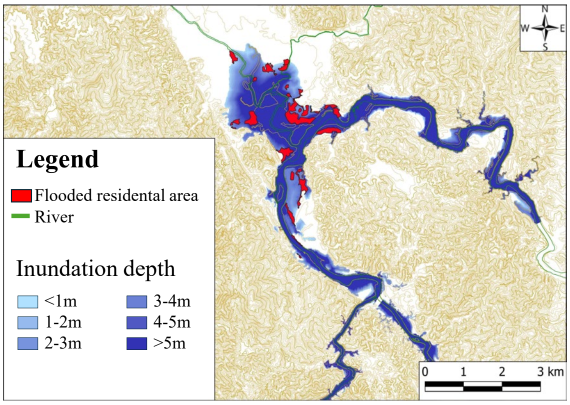

Fig. 11. Inundation boundary map and flooded residential areas corresponding to the most severe flooding scenario P1.3.

The flood discharge scenario with exceeding test flood (P1.3) causes the largest downstream flood (12.73 km^2), with 78.42 hectares of flooded houses. The dam break scenario due to an earthquake in normal (non-rainy) weather conditions (P2.1) causes the smallest flood (6.78 km^2), with 10.9 hectares of flooded houses.

Table 3. Inundation simulation results of all scenarios and the comparison between P1.1 and P2.2

Scenario	Description	Inunation area (km^2)	Elevation at inundation area (m)	Depth (m)	Volume (1000 m^3)	Inundation residential area (ha)
P1.1	Active flood discharge with design flood	9.4	152	8.03	7,306	47.45
P1.2	Active flood discharge with test flood	12.02	153.9	9.97	15,961	72.17
P1.3	Active flood discharge with flood frequency exceeding test flood	12.73	154.8	10.87	19,176	78.42
P2.1	Dam break due to earthquake in normal weather conditions	6.78	150.8	6.81	862	10.90
P2.2	Dam break during an active flood discharge with design flood	10.33	153.1	9.08	8,538	53.37
P2.2 vs P1.1		9.89%	0.69%	13.08%	16.86%	12.47%

The comparison between the active flood discharge scenario with design flood (P1.1) and the dam break scenario during an active flood discharge with design flood (P2.2) shows that the dam break increased the flooded area by 0.93 km^2 (9.89%), the flooded depth by 1.05 m (13.08%), the water volume increased by 1,232 thousand m^3 (16.86%), and the flooded residential area increased by 5.9 ha (12.47%).

The most serve flood scenerio (P1.3) shows that most of flood residental areas are in That Khe town (Fig 11). Therefore it is recommended to focus on That Khe town and the red area on the map on Fig. 11 to develop flood prevention plans, constructing protective works, and planning evacuation.

5. CONCLUSION

The paper has simulated the flood inundation model at downstream of Thac Xang hydropower dam (capacity 20MW) due to flood discharge and dam break. The simulation model has combined the 1D river hydraulic model and the 2D flow area model. The reservoir model firstly connects to the Bac Giang River model by the hydropower dam model, then the Bac Giang River merges with the Ky Cung river and connects to the 2D flow model at the section passing through That Khe town.

The paper has simulated three (03) active flood discharge processes corresponding to flood with exceedance probability of 1%, 0.2%, 0.1% and two (02) dam break incidents. The simulation model is skipping the optimal reservoir operation process for power generation purposes, prioritizing safe operation of the project, minimizing flooding downstream by proactively opening the discharge gate early to receive floods. The model is verified with the flood discharge design parameters of the plant, giving quite similar results with a difference of 0.14~0.28m for downstream water levels and 0.2~1.8m for upstream water levels.

Simulation results of flood discharge processes show that Thac Xang hydropower is a small one and limited regulation capacity, the ability to reduce flood peaks by 6.54%; flood peak times are delayed by 1~1.8 hours. When the hydropower dam breaks during active flood discharge (with design flood), the flooded area will increase by 9.89%, the flooded residential area will increase by 12.47% and the flooded depth will increase by 13.08% in the same time.

Based on these results, the next step of the research will be to verify and modify the model results by using collected data (by investigating historical flood traces). The flood maps, especially the zoning of flooded residential areas as shown in Fig. 11, can be used as a basis for developing flood prevention plans, constructing protective works, and planning evacuation.

6. REFERENCES

[1] Breeze P. A., Hydropower. London, England: Academic Press, 2018, pp.1-104.

[2] Kaygusuz K., Hydropower as clean and renewable energy source for electricity generation. Journal of Engineering Research and Applied Science, Vol. 5, Issue 1, Jun. 2016, pp. 359–369.

[3] PM Decision 500/QD-Ttg dated on May 15, 2023 on Approving the National Power Development Plan for the 2021-2030 period, with a vision to 2050. Accessed: Sep. 19, 2024. [Online]. Available: https://vepg.vn/wp-content/uploads/2023/05/PDP8_full-with-annexes_EN.pdf. pp. 1-83.

[4] The world bank, Small Hydro Resource Mapping in Vietnam, Mar. 2017. Accessed: Oct. 07, 2024. [Online]. Available: https://documents1.worldbank.org/curated/pt/246471504701826323/pdf/119400-V1-ESMAP-P145513-PUBLIC-VietnamHydropowerMapping.pdf. pp 1-154.

[5] Sachdev H. S., Akella A. K., and Kumar N., Analysis and evaluation of small hydropower plants: A bibliographical survey. Renewable and Sustainable Energy Reviews, Vol. 51,

2015, pp. 1013–1022, doi: 10.1016/j.rser.2015.06.065.

[6] Kusuma M. S. B., Setiawati T., and Farid M., Experimental Model of Dam Break Flow Around Several Blockages Configurations. International Journal of GEOMATE, Vol. 16, Issue 58, Nov. 2021, pp. 26–32.

[7] Gee D. M. and Brunner G. W., Dam Break Flood Routing Using HEC-RAS and NWS-FLDWAV, American Society of Civil Engineers, Apr. 2012, pp. 1–9. doi: 10.1061/40792(173)401.

[8] Ansori M. B., Damarnegara A. A. N. S., Margini N. F., and Nusantara D. A. D., Flood Inundation and Dam Break Analysis for Disaster Risk Mitigation (a Case Study of Way Apu Dam). International Journal of GEOMATE, Vol. 21, Issue 84, Nov. 2021, pp. 85–92.

[9] Rizaldi A., Aribawa T. M., Mardjono A., Soegiarto S., Moe I. R., Sihombing Y. I., and Farid M., Assessment of Flood Propagation Due to Several Dams Break in Banten Province. International Journal of GEOMATE, Vol. 20, Issue 81, Nov. 2021, pp. 185–190.

[10] Kiwanuka M., Chelangat C., Mubialiwo A., Lay F. J., Mugisha A., Mbujje W. J., and Mutanda H. E., Dam breach analysis of Kibimba Dam in Uganda using HEC-RAS and HEC-GeoRAS. Environmental Systems Research, Vol. 12, Issue 1, Oct. 2023, p. 31, doi: 10.1186/s40068-023-00317-4.

[11] Bharath A., Shivapur A. V., Hiremath C. G., and Maddamsetty R., Dam break analysis using HEC-RAS and HEC-GeoRAS: A case study of Hidkal dam, Karnataka state, India. Environmental Challenges, Vol. 5, Dec. 2021, p. 100401, doi: 10.1016/j.envc.2021.100401.

[12] Pilotti M., Milanesi L., Bacchi V., Tomirotti M., and Maranzoni A., Dam-Break Wave Propagation in Alpine Valley with HEC-RAS 2D: Experimental Cancano Test Case. Journal of Hydraulic Engineering, Vol. 146, Issue 6, Jun. 2020, p. 05020003, doi: 10.1061/(ASCE)HY.1943-7900.0001779.

[13] Al-Salahat M., Al-Weshah R., and Al-Omari S., Dam break risk analysis and flood inundation mapping: a case study of Wadi Al-Arab Dam. Sustain. Water Resour. Manag., Vol. 10, Issue 2, Mar. 2024, p. 74, doi: 10.1007/s40899-024-01051-0.

[14] Using HEC-RAS for Dam Break Studies. US Army Corps of Engineers, Institute for Water Recources, Hydraulic Engineering Center. 2014. Accessed: Sep. 19, 2024. [Online]. Available: https://www.hec.usace.army.mil/publications/TrainingDocuments/TD-39.pdf. pp. 1-74.

[15] HEC-RAS, River Analysis System-Hydraulic User's Manual. US Army Corps of Engineers, Hydrologic Engineering Center. 2016. Accessed: Sep. 19, 2024. [Online]. Available: https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Users%20Manual.pdf. pp.1-960.

[16] HEC-RAS User's Manual. Accessed: Sep. 20, 2024. [Online]. Available: https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest. pp.1-768.

[17] Technical standard: TCKT 03:2015/TCTL Hydraulic works - Guidelines for developing flood maps downstream of reservoirs in emergency flood discharge and dam break situations. Ministry of Agriculture and Rural Development, 2015. pp.1-46.

[18] Technical standard: TCVN 13615:2022 - Calculation of Design Hydrological Elements. Ministry of Agriculture and Rural Development, 2020. pp 1-205.