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The Study of the impact of water channel obstructions in the lower Mun River on flooding

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ABSTRACT

In 2022, Ubon Ratchathani Province experienced severe flooding that caused extensive damage to local communities. Local public opinion attributed the severity of this event to flow obstructions in the Mun River, particularly Kaeng Saphue and the Pak Mun Dam. These structures have raised concerns regarding their potential impacts on flood hydraulics. To explore this idea, this study will look at how these barriers affect flooding downstream using the HEC-RAS 2D hydrodynamic model. The simulation domain covers the river's reaches from the confluence of the Chi and Mun Rivers to the point where the Mun River flows into the Mekong River. The 2022 flood hydrograph was used to simulate flood extent and water levels under scenarios with and without the obstructions, including four different cases. Model calibration and validation were performed using data from 2019 and 2022, yielding high accuracy with R^2 values of 0.964 and 0.978, and RMSE values of 0.14 and 0.057, respectively. The study found that the water level at station M.7 was 116.50 m MSL in both the scenario with Kaeng Saphue and the Pak Mun Dam (OB.1) and the scenario without the Pak Mun Dam (OB.3), indicating no difference between these two cases. In contrast, removal of Kaeng Saphue (OB.2) reduced the water level to 116.15 m MSL, and removal of both obstructions (OB.4) further lowered it to 115.92 m MSL. These results indicate that Kaeng Saphue plays a significant role in raising water levels at station M.7, while the Pak Mun Dam has a secondary effect. When Kaeng Saphue is removed, the Pak Mun Dam becomes the primary obstruction contributing to upstream water level increases. This highlights the hydraulic influence of both natural and man-made obstructions in exacerbating flood impacts along the Mun River.

Keywords: HEC-RAS 2D model, Mun River flood 2022, Channel obstruction, Kaeng Saphue rapid, Pak Mun Dam

INTRODUCTION

Ubon Ratchathani Province experiences the problem of the Mun River overflowing its banks and flooding low-lying areas along it almost every year. This is due to the province's location at the confluence of the Mun and Chi Rivers, which are major river basins. Persistent heavy rainfall in these basins results in a substantial inflow of water into low-lying areas adjacent to the river, affecting residential communities, economic zones, and critical transportation routes. The Mun River, the only river that drains into the Mekong River, exacerbates this situation due to its limited drainage capacity.

The Mun River in the lower reaches of Phibun Mangsahan District is characterized by numerous islands and rapids throughout much of its length. In particular, Kaeng Saphue is a large natural rock rapid that forms a raised rocky and soil formation, almost completely obstructing the cross-section of the river and significantly impeding water flow. The average rock elevation of Kaeng Saphue is 106.25 m MSL, approximately 5.57 m above the normal water level. Water levels at Kaeng Saphue fluctuate irregularly with alternating heights. Due to this characteristic, Kaeng Saphue functions like a water retention dam, causing elevated water levels and reducing flow velocity. During the flood season, Kaeng Saphue acts as a major obstacle to water discharge, slowing the drainage of the Mun River into the Mekong River and worsening flooding in low-lying areas [1, 2], especially in Warin Chamrap and Ubon Ratchathani Municipalities.

Additionally, the Pak Mun Dam is located at Ban Huahew, Khong Chiam District, Ubon Ratchathani Province, approximately 6 kilometers upstream from the confluence of the Mun River and the Mekong River. This water diversion dam, constructed from compacted concrete, stands 17 meters high and extends 300 meters in length, featuring a crest 6 meters wide at an elevation of 111.0 m MSL. The dam's water drainage system consists of eight channels, each equipped with a radial gate measuring 22.5 meters wide and 14.75 meters high, allowing a maximum discharge capacity

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of 18,500 cubic meters per second. The Pak Mun Dam provides numerous benefits, including stabilizing electricity production in the Northeast Region, supplying water for a 150-kilometer irrigation system upstream, supporting the Khong-Chi-Mun Project, establishing a fish breeding center to promote fisheries development, and serving as a tourist attraction [3]. However, the Pak Mun Dam is often cited as an obstacle to water drainage in the Mekong River. Since the dam was built to block the river's original width of approximately 300 meters, only 180 meters of the river can be drained through its eight gates, each 22.5 meters wide. This limited drainage capacity has been identified as a contributing factor to flooding in Ubon Ratchathani Province [4, 5].

The 2022 flood was triggered by a strong monsoon trough passing through the northeastern region and by Tropical Depression Noru, which entered Thailand near Khong Chiam District, Ubon Ratchathani Province, on the evening of September 28, 2022. At that time, it remained a depression. The storm then moved across Amnat Charoen, Yasothon, Roi Et, Maha Sarakham, and Khon Kaen Provinces, before weakening into a low-pressure cell over Chaiyaphum Province on the evening of September 29, 2022. The influence of the storm brought heavy to very heavy rainfall to the affected and surrounding areas, with particularly intense rainfall recorded in many parts of Ubon Ratchathani Province. This caused the water levels in the Mun River and its tributaries to rise continuously, leading to widespread overflow along nearly the entire river. At Station M.7 in Warin Chamrap District, the highest water level was recorded at 116.51 m MSL, with a peak discharge of 6,071 m^3/s. As a result, regularly inundated low-lying areas experienced severe flooding, particularly in Warin Chamrap District, where flood levels rose above 4 meters. The flooding extended into the Ubon Ratchathani urban area, an important economic hub for both the province and the broader region located at the edge of the flooded zone. Many public utilities and almost all major access routes into Ubon Ratchathani City were severely flooded, including the Seri Prachathipatai 200 Years Bridge, the western bypass (Highway No. 231), and Highways No. 226 and 23. The only remaining main access route was the eastern bypass (Highway No. 231), which connects Warin Chamrap District to Ubon Ratchathani City [6, 7].

This research reviews relevant studies on flood volume analysis, flood simulation, and the impact of flow obstructions. Previous studies include the following: For instance, a study conducted in 2019 employed the InfoWorks-ICM model to simulate flooding in the Mun River in Ubon Ratchathani Province, with a focus on Mueang District. The study found that the river's roughness coefficient ranged from 0.03 to 0.065. The calibration results were accurate and reliable, making the model suitable for various applications [2]. Another study on flood prevention guidelines in Ubon Ratchathani Province, particularly in the lower Mun River Basin, reported that the river's roughness coefficient ranged from 0.028 to 0.045 [8]. Additionally, a study on the effects of flow obstructions on river flooding found that such obstructions can cause higher-than-normal flood levels and increased upstream inundation distances [9]. Several studies have explored approaches to mitigating flood problems in rivers and streams: A study on flood alleviation in small streams found that structural measures alone could not fully resolve flood issues. Researchers found that the most effective approach to reducing flood levels was to improve the cross-sections of bridges and culverts [10]. A working group investigating flood conditions and solutions in Mueang District, Ubon Ratchathani, proposed multiple drainage strategies for the Mun River. These included diverting floodwater through a natural canal to the Lam Dom Yai River, excavating a shortcut canal to bypass rapids, and improving islands and rapids in the downstream section. The results indicated that improving islands and rapids yielded the greatest reduction in flood levels-by approximately 162 to 169 cm [11]. A study examining the impact of flooding on built-up areas and infrastructure in Nan City found that raising land levels in flood-prone areas exacerbated flooding. Elevated land obstructed drainage, resulting in higher and longer-lasting floodwater levels [12]. The Marine Department conducted a detailed dredging design study for the Mun River, covering its course from Chok Chai District in Nakhon Ratchasima to its confluence with the Mekong River. Areas with environmental conservation restrictions were excluded. The study found that maximum flood levels could be reduced by an average of approximately 90 cm. In Mueang Ubon Ratchathani and Warin Chamrap Districts, flood levels decreased by 51–59 cm, while the greatest reduction-up to 99 cm-was recorded in Phibun Mangsahan District [13]. Another study assessed the impact of floodplain woodland on flood flows. Results showed that establishing woodland in floodplain areas significantly reduces downstream flood risk. Increased hydraulic roughness from vegetation slows flood velocities, raises upstream water levels, and enhances flood storage capacity. These combined effects help attenuate flood peaks and reduce flood intensity, offering a natural method for flood mitigation [14]. Lastly, a study in the Yellow River Basin examined the influence of multiple cross-river structures on flood discharge in mountain rivers. It found that removing weirs reduced maximum backwater levels by approximately 1.09 to 1.14 meters. Lowering weir crest elevations also decreased upstream water levels but did not substantially improve flood discharge capacity. Conversely, bridges, particularly those with piers, significantly affected flood dynamics. Submerged slab and arch bridges contributed to upstream backwater effects, with slab bridges having a more pronounced

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impact. The number of bridge openings and pier thickness were found to be directly correlated with flow obstruction and the river's flood discharge capacity [15].

The objective of this research is to analyze the impact of flow obstructions in the lower Mun River, specifically Kaeng Saphue and the Pak Mun Dam, on flood levels in Ubon Ratchathani Province. This was accomplished using the HEC-RAS 2D model to simulate the 2022 flood event. The study compared scenarios with and without these obstructions to determine the extent to which they contribute to overflow flooding from the Mun River. A 2D model was selected for its ability to accurately capture inundation both within the river channel and in overbank areas. The model's accuracy was enhanced by updating the Digital Elevation Model (DEM) with newly surveyed cross-sectional data from 2020 and 2024, including detailed topographic information about Kaeng Saphue. Additionally, mesh sizes of 5 to 10 meters were applied in areas with significant elevation variation, such as dikes, flow paths, and uneven riverbeds, to improve simulation precision.

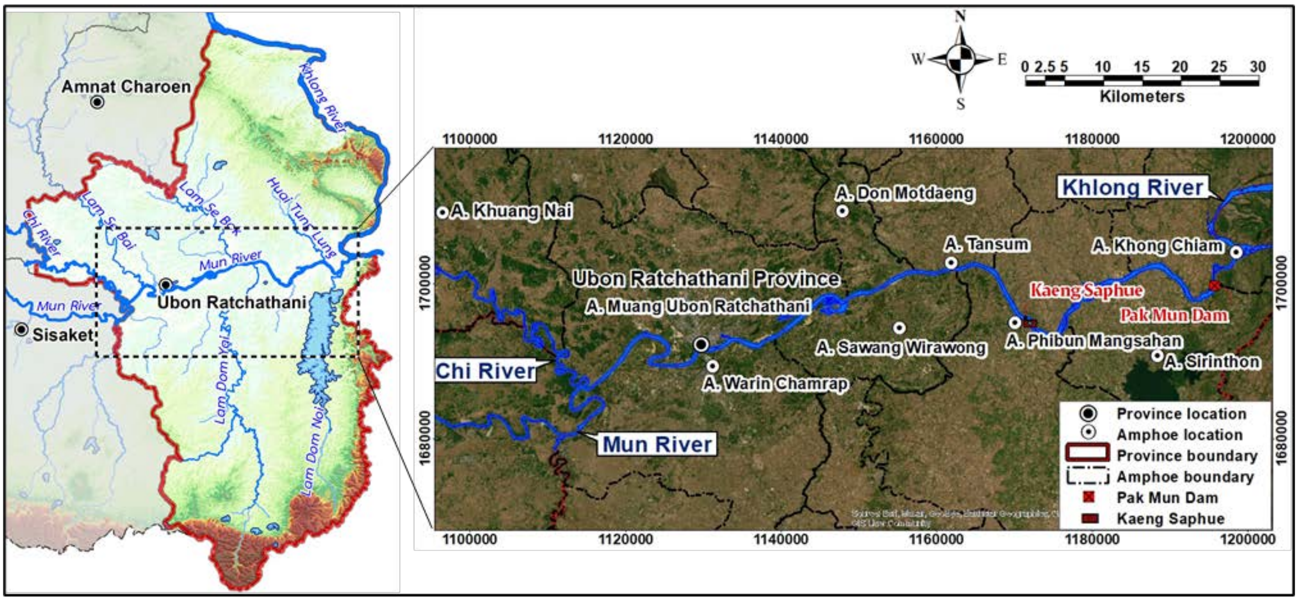

Figure 1 Study area along the Mun River in Ubon Ratchathani Province.

MATERIALS AND METHODS

The study area encompasses the Mun River and its adjacent floodplains in Ubon Ratchathani Province, located in the lower Mun River Basin. It extends from the confluence with the Chi River at UTM Zone 48N 469269 E, 1678548 N to its junction with the Mekong River at UTM Zone 47N 1199499 E, 1703776 N, covering a distance of approximately 116 kilometers. The area includes nine districts situated along and impacted by the Mun River: Khueang Nai, Mueang Ubon Ratchathani, Warin Chamrap, Sawang Wirawong, Don Mod Daeng, Tan Sum, Phibun Mangsahan, Sirindhorn, and Khong Chiam (Figure 1).

The steps for hydraulic analysis with the HEC-RAS 2D model involve gathering data, building the model, adjusting and checking the model, and using the model for case study analysis, as explained below.

1. Data collection

Data collection included gathering existing information from government agencies, such as river shapes, Digital Elevation Models (DEMs), weather and water data, land use details, and anything that blocks water flow (Table 1).

2. HEC-RAS model setup

This study utilized the HEC-RAS model version 6.4.1, developed by the Hydrologic Engineering Center (HEC) for the U.S. Army Corps of Engineers. The model analyzes flow in both one-dimensional (1D) and two-dimensional (2D) domains, supporting steady and unsteady flow calculations for water surface profiles, combined 1D and 2D hydrodynamics, and spatial mapping of parameters such as depth, water surface elevation, and velocity [16]. The 2D model simulates changing flow by using the shallow water (Saint-Venant) equations, which explain how mass is conserved and how momentum works in both the x and y directions, considering factors like gravity, pressure, friction, and forces from movement. It calculates water depth and velocity at each cell in a computational mesh, enabling accurate simulation over complex terrain.

HEC-RAS 2D uses a method that divides space into small sections, like squares, rectangles, or triangles, to solve equations on a grid that isn't perfectly regular. The model supports complex boundary conditions, internal structures, and terrain features, making it highly suitable for simulating floods in riverine channels and overbank areas [16, 17].

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Table 1 Data inputs for the HEC-RAS 2D model.

Type of Data	Details	Source
River Network	Mun and Chi Rivers, including tributaries Huai Khayung, Huai Pub, Lam Dom Yai, Lam Dom Noi, Lam Sebai, Lam Sebok, Huai Tung Lung	Office of National Water Resources (ONWR), Royal Irrigation Department (RID)
Longitudinal Profiles	Longitudinal profiles of Mun and Chi Rivers	ONWR, RID
River Cross-Sections	Cross-sectional data of the Mun and Chi Rivers, including major tributaries and cross-sections near Pak Mun Dam	ONWR, RID, EGAT
Digital Elevation Model (DEM)	1:4,000 scale with 5×5 meter grid resolution representing off-river surface elevation	Land Development Department
Meteorological Data	Daily evaporation from Yasothon, Si Sa Ket, and Ubon Ratchathani weather stations and rainfall data	Meteorological Department
Hydrological Data	Runoff from gauging stations E.20A, M.182, M.170, M.176, M.157, M.32, M.69, 020139; water level and rating curves at M.7 and Sirindhorn Dam discharge data	RID, DWR, EGAT
Land Use Data	Used for selection of Manning's roughness coefficient (n)	Land Development Department
Flow Obstruction Data	2024 survey of Kaeng Saphue by RID; river cross-sections of Pak Mun Dam area (pre-construction and headworks)	RID, EGAT

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = q \qquad (1)$$

$$\frac{\partial V}{\partial t} + (V.\nabla)V + f_c k \times V = -g\nabla z_s + \frac{1}{h}\nabla.(v_t h \nabla V) - \frac{\tau_b}{\rho R} + \frac{\tau_s}{\rho h} \qquad (2)$$

Where,

t = time
h = water depth
u and v = velocity components in the and directions respectively
q = source/sink flux term (source > 0, sink < 0)
g = gravitational acceleration
z_s = water surface elevation
R = hydraulic radius
ρ = water density
f_c = Coriolis parameter
V = velocity vector
k = unit vector in the vertical direction
v_t = the eddy viscosity tensor
τ_b = bottom shear stress vector
τ_s = wind surface stress vector
∇ = gradient operator given by $\partial/\partial x$, $\partial/\partial y$

The HEC-RAS model set up for this research is divided into 5 main parts: data verification, terrain generation, 2D flow area generation, Manning's roughness coefficients assignment, boundary condition application, and flow obstruction sections import, as detailed below (Figure 2).

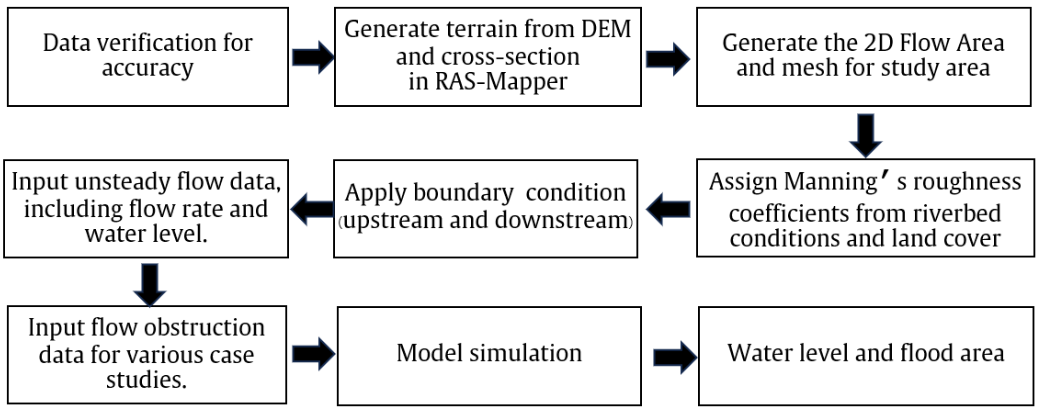

Figure 2 HEC-RAS 2D model development diagram.

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2.1 The accuracy of rainfall data was verified using the Double Mass Curve method by plotting the cumulative rainfall of the index station against that of nearby stations. The consistency of streamflow data was assessed through cross-checking with data from adjacent stations. Additionally, the accuracy of the Digital Elevation Model (DEM) was verified by comparing elevation values with topographic survey data.

2. 2 Initial terrain data was derived from the Digital Elevation Model (DEM) provided by the Land Development Department. To improve the accuracy of the river areas, survey results of river cross-sections, gathered from the Office of National Water Resources and the Royal Irrigation Department, were used to make a more detailed DEM just for the river sections (Figure 3). This refined river DEM was then integrated with the original Land Development Department DEM to produce a new, adjusted DEM. This final DEM, featuring refined elevation values, served as the primary elevation data for the entire study area.

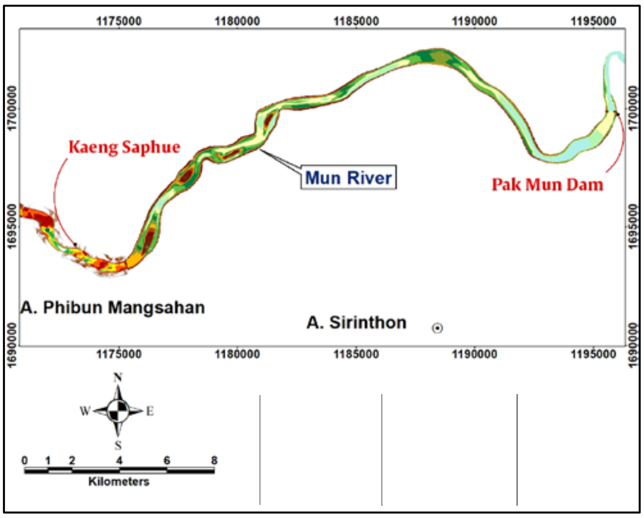

Figure 3 DEM from Kaeng Sapue to Pak Mun Dam.

2.3 The boundary conditions for flow simulation (2D Flow Areas) were defined to cover the study area, consistent with the research objectives and collected data. The mesh size within the 2D flow areas was determined based on the computational elements. While a smaller mesh yields more accurate results, it significantly increases computation time. Conversely, a larger mesh reduces calculation time but at the expense of accuracy. Thus, the strategy involved initiating with a coarser mesh and progressively refining its size to achieve greater detail in areas of interest or critical importance. For this research, mesh sizes ranged from 5x5 meters to 100x100 meters.

2.4 Accurate assignment of Manning's roughness coefficients (n) is crucial for precise calculations water surface elevation calculations. Initial determination of Manning's n values was based on experimental recommendations for various river conditions [17]. The Mun River is characterized by meanders, potholes, and areas with vegetation and rock covers. As a result, the recommended Manning's n values for these conditions typically range from 0.033 to 0.045 [18]. A review of previous research on similar river types has also found values in the broader range of 0.028 to 0.065 [2, 8]. For areas outside the river channel, the Manning's n values were determined based on recommended values according to land use types, as shown in Table 2.

2.5 The boundary conditions applied in the model consisted of upstream inflow and downstream outflow conditions. Upstream inflow conditions were based on water volume data gathered from seven measuring stations (E.20A, M.182, M.32, M.157, M.170, M.69, M.110) and flow data from Sirindhorn Dam. Additionally, the runoff from sub-basins within the 2D Flow Areas was incorporated as lateral inflow (side flow). The downstream condition utilized water level data from gauging station 020139, located on the Mekong River at Khong Chiam District.

Table 2 The roughness coefficient (Manning's n).

Type of channel	Minimum	Normal	Maximum
1. Main Channel			
a. clean, straight, full stage, no rifts or deep pools, more stones and weeds	0.030	0.035	0.040
b. clean, winding, some pools and shoals	0.033	0.040	0.045
c. same as above, but some weeds and stones	0.035	0.045	0.050
2. Flood plains			
a. Light brush and tree in summer	0.04	0.06	0.08
b. Developed, high intensity	0.12	0.16	0.20
c. Developed, medium intensity	0.08	0.12	0.16
d. Developed, low intensity	0.06	0.09	0.12

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3. Model calibration and validation

HEC-RAS model calibration and validation aim to identify the appropriate model parameters. We selected the Manning's n value. The friction value for open channel flow is represented by the Manning's roughness coefficient. We selected the Manning's n value based on the characteristics of the study area. This selection involved comparing the area's properties with recommended ranges from existing manuals [17] and iteratively testing the value with the model until an appropriate fit was achieved. The model was changed and verified for accuracy using statistical methods, particularly the Coefficient of Determination (R^2) and the Root Mean Square Error (RMSE), as shown in Equations (4) and (5). This process aimed to ensure the model's fidelity to real-world conditions.

$$R^2 = \left\{\frac{\sum_{i=1}^{N}(Q_{Oi}-\bar{Q}_O)\times(Q_{Si}-\bar{Q}_S)}{\left[\sum_{i=1}^{N}(Q_{Oi}-\bar{Q}_O)^2\times\sum_{i=1}^{N}(Q_{Si}-\bar{Q}_S)^2\right]^{0.5}}\right\} \tag{4}$$

$$RMSE = \left\{\frac{\sum_{i=1}^{N}(Q_{Oi}-Q_{Si})^2}{N}\right\}^{0.5} \tag{5}$$

When,

N = Number of data
Q_O = Observed water level at any time
$\bar{Q}_O$ = Average observed water level
Q_S = Modeled water level at any time
$\bar{Q}_S$ = Average modeled water level

This study utilized water level data from the M.7 gauging station on the Mun River (Seri Prachathipatai Bridge, Ubon Ratchathani Province) for model calibration (August-October 2019) and validation (August-November 2022). These periods included both flood events and intervals when the Royal Irrigation Department had suspended regulator gate operations, ensuring that water levels and volumes were unaffected by gate-related management. The accuracy of calibration and validation was then assessed using statistical metrics: the Coefficient of determination (R^2) and the root mean square error (RMSE). An R^2 value greater than 0.6 and an RMSE value close to zero typically indicate a strong positive correlation between observed and modeled water levels. Therefore, the selected roughness coefficient was considered acceptable [19, 21].

4. Study of flow obstruction impacts

The downstream section of the Mun River, particularly in Phibun Mangsahan District, is characterized by numerous rapids of varying sizes along almost its entire length, which obstruct water flow. Kaeng Saphue, a major rapid, spans the entire width of the Mun River. Further downstream lies the Pak Mun Dam. These features raise suspicions that the dam obstructs the waterway and contributes to severe flooding in Ubon Ratchathani Province [4, 5]. Consequently, the researcher aims to investigate the impact of flow obstructions in the Mun River, focusing on the identified primary problem areas: Kaeng Saphue and the Pak Mun Dam. The study divides the analysis of flow obstructions into four distinct cases (Figure 4).

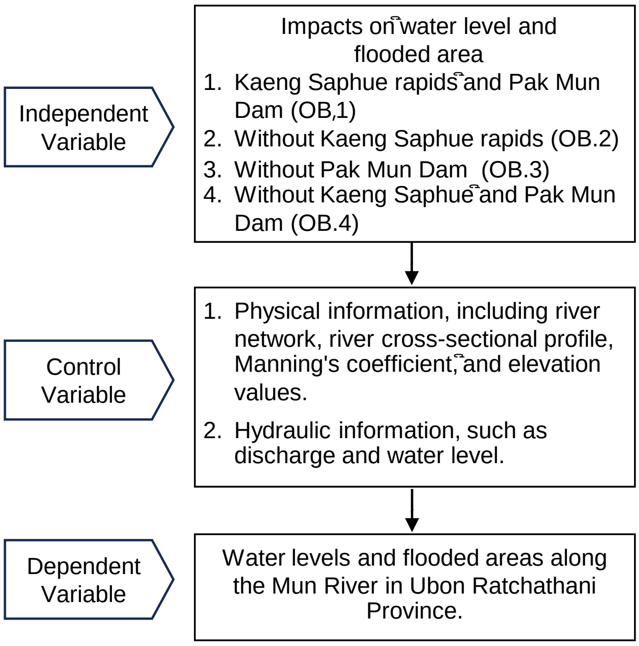

Figure 4 Conceptual framework in research.

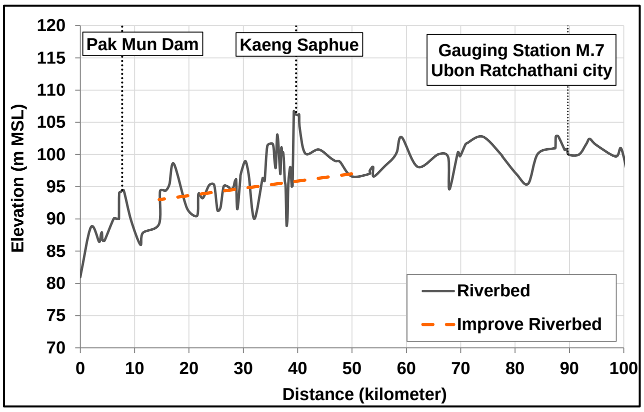

Figure 5 Longitudinal profile of riverbed before and after improvement at Kaeng Sapue.

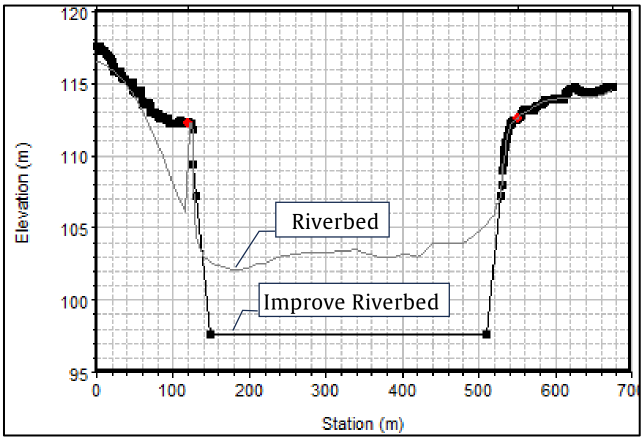

Figure 6 Riverbed cross-section before and after improvement at Kaeng Sapue.

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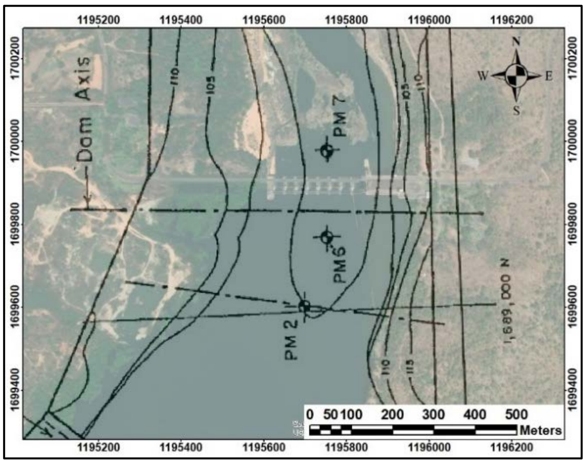

Before and after images of the Pak Mun Dam

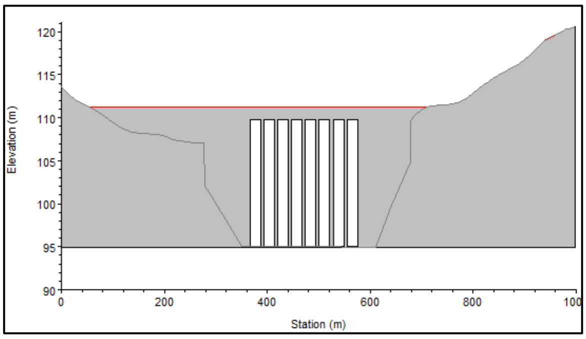

Figure 7 River cross-section after Pak Mun Dam construction.

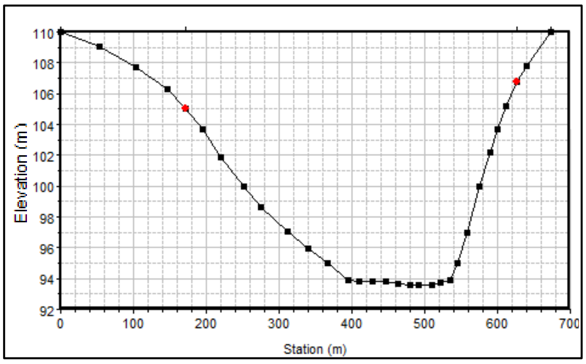

Figure 8 River cross-section before Pak Mun Dam construction.

The study case was set as the independent variable for analyzing the impact of flow obstructions across all four cases, while the same control variables were consistently applied. Physical data for the study area included the river network, river cross-sections (excluding the Kaeng Saphue and Pak Mun Dam areas), and elevation data. Hydrological data comprised flow discharge and water levels. The dependent variables obtained from this analysis were the resulting water levels and flooded areas along the Mun River in Ubon Ratchathani Province.

The HEC-RAS model was applied to simulate the effects of flow obstructions on water levels and flooded areas. The study area covered the Mun River from the M.182 gauging station (Kanthararom District, Sisaket Province) and the Chi River from the E.20A gauging station (Maha Chanachai District, Yasothon Province), extending downstream to the Mekong River at Khong Chiam District, Ubon Ratchathani Province. The 2022 flood hydrograph was used as input for the inundation simulation.

These cases comprise:

4.1 Impact with Kaeng Saphue and the Pak Mun Dam present (current condition) (OB.1): This case assumes the existing morphology of both Kaeng Saphue and the Pak Mun Dam in the Mun River remains unchanged. (Figures 5 to 7).

4.2 Impact without Kaeng Saphue (OB.2): Derived from Case 1, this case involves removing Kaeng Saphue by improving the riverbed slope at Kaeng Saphue. We achieved this by using the normal water level value before and at the end of Kaeng Saphue, which led to an approximate riverbed slope of 1:12,000. (Figures 5 and 6).

4.3 Impact without the Pak Mun Dam (OB.3): This case, based on Case 1, looks at what happens if the Pak Mun Dam is taken away, meaning the Mun River in that area will go back to its original shape before the dam was built (Figure 8).

4.4 Impact without both the Pak Mun Dam and Kaeng Saphue (OB.4): This case combines the improvements from Case 2 (riverbed slope at Kaeng Saphue) and the original river cross-section in the Pak Mun Dam area as in Case 3.

RESULTS AND DISCUSSION

1. HEC-RAS model calibration and validation results

Prior to calibrating the Manning's roughness coefficient, a sensitivity analysis was performed by varying the n value within a range of ±5% to ±20%. The results showed that the maximum water level varied by no more than 0.15 meters (Figure 9), indicating that the model is relatively insensitive to small changes in roughness within this range.

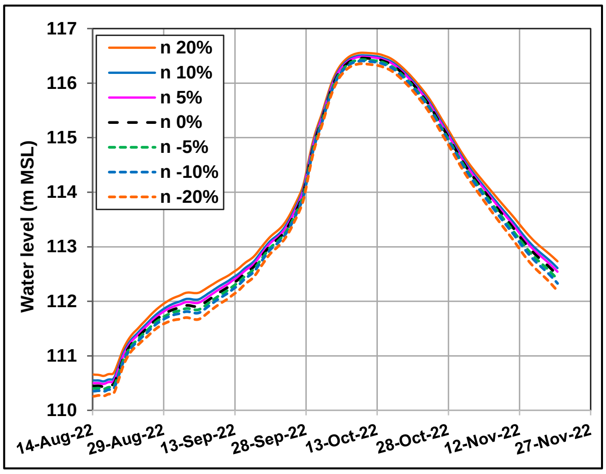

Figure 9 Sensitivity analysis results for Manning's roughness coefficient at M.7.

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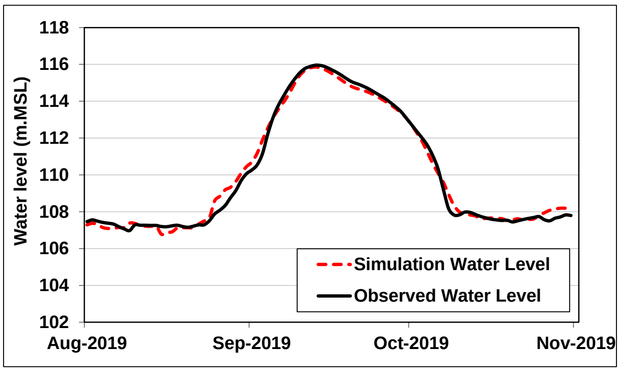

Figure 10 Comparison of observed and simulated water levels for calibration at M.7.

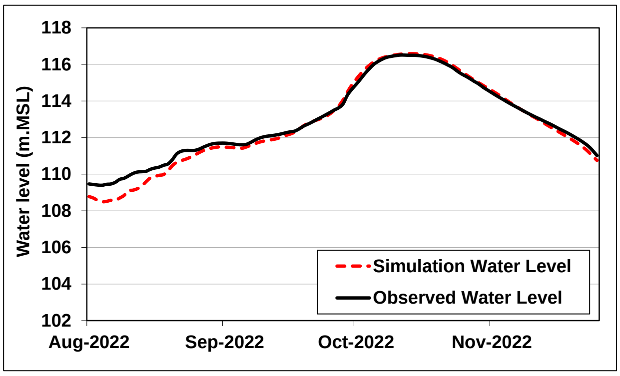

Figure 11 Comparison of observed and simulated water levels for validation at M.7.

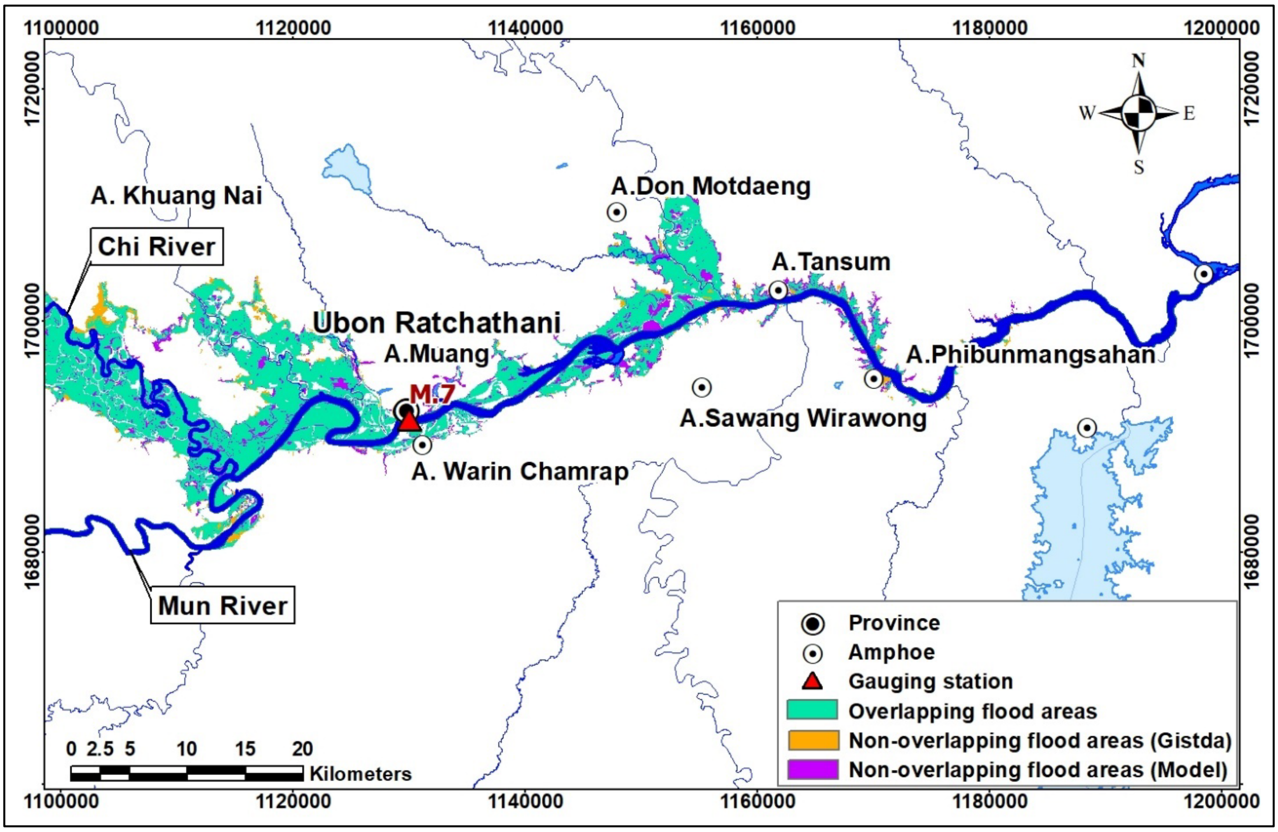

Figure 12 Spatial overlap between modeled inundation and GISTDA flood mapping.

Model calibration used 2019 water level data from the Mun River at gauging station M.7. The calibrated Manning's roughness coefficients (n) were 0.040 for normal river sections and 0.045 for rapids (Figure 10), yielding R^2 = 0.964 and RMSE = 0.140 m.

Model validation employed 2022 water level data (Figure 11), resulting in R^2 = 0.978 and RMSE = 0.057 m. These values met acceptance criteria (R^2 > 0.6, RMSE close to 0).

A comparison of the model-simulated flooded area with satellite imagery from GISTDA for the 2022 flood event in Ubon Ratchathani Province showed a strong agreement. The model predicted an inundated area of 483.58 sq.km., while GISTDA reported 441.40 sq.km., with an overlapping area of 408.44 sq.km., accounting for 92.53% of the GISTDA-derived flooded area (Figure 12). Discrepancies are mainly due to differences in flood extent interpretation: GISTDA excludes water bodies and wetlands, whereas the model removes only major channels and reservoirs. Additionally, limited gauging data in some areas, such as near Kaeng Saphue, may contribute to differences in simulated flood extents.

2. Results of the application of HEC-RAS model in studying the impact of flow obstructions.

The study of the four cases during the 2022 flood showed that obstacles in the water flow raised water levels much higher than in situations without these obstacles (Figures 13 and 14). The observed elevation differences extended approximately 114 kilometers along the Mun River, leading to inundation in areas from Khueang Nai District to Phibun Mangsahan District.

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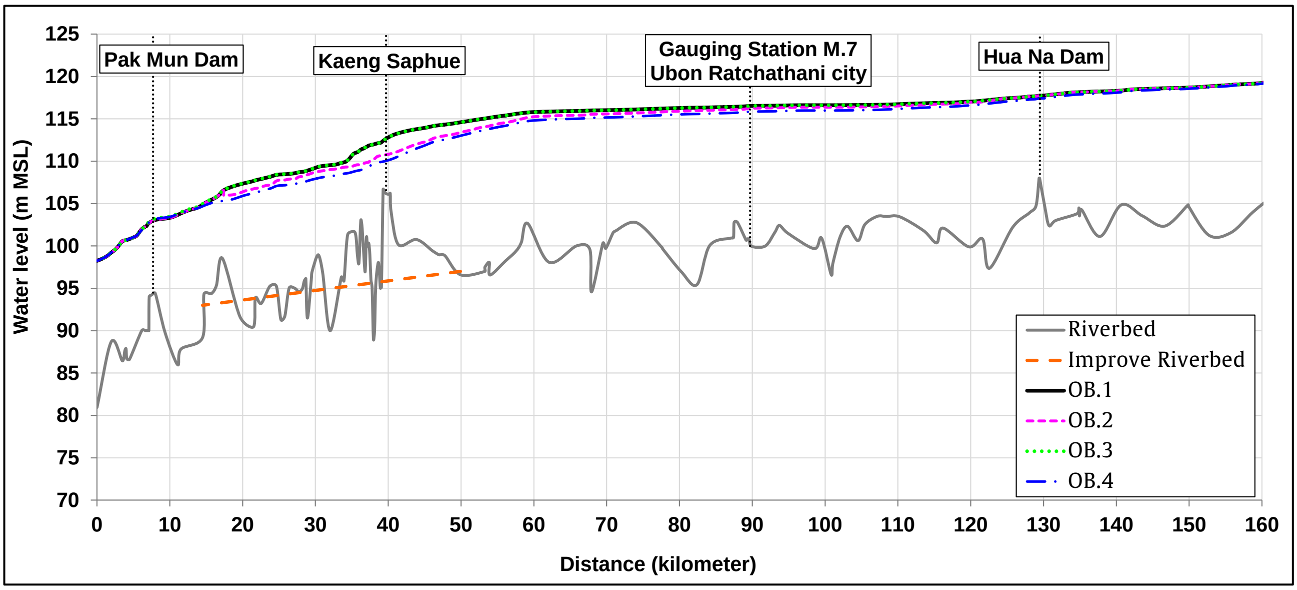

Figure 13 Simulated water levels in the Mun River under various cases.

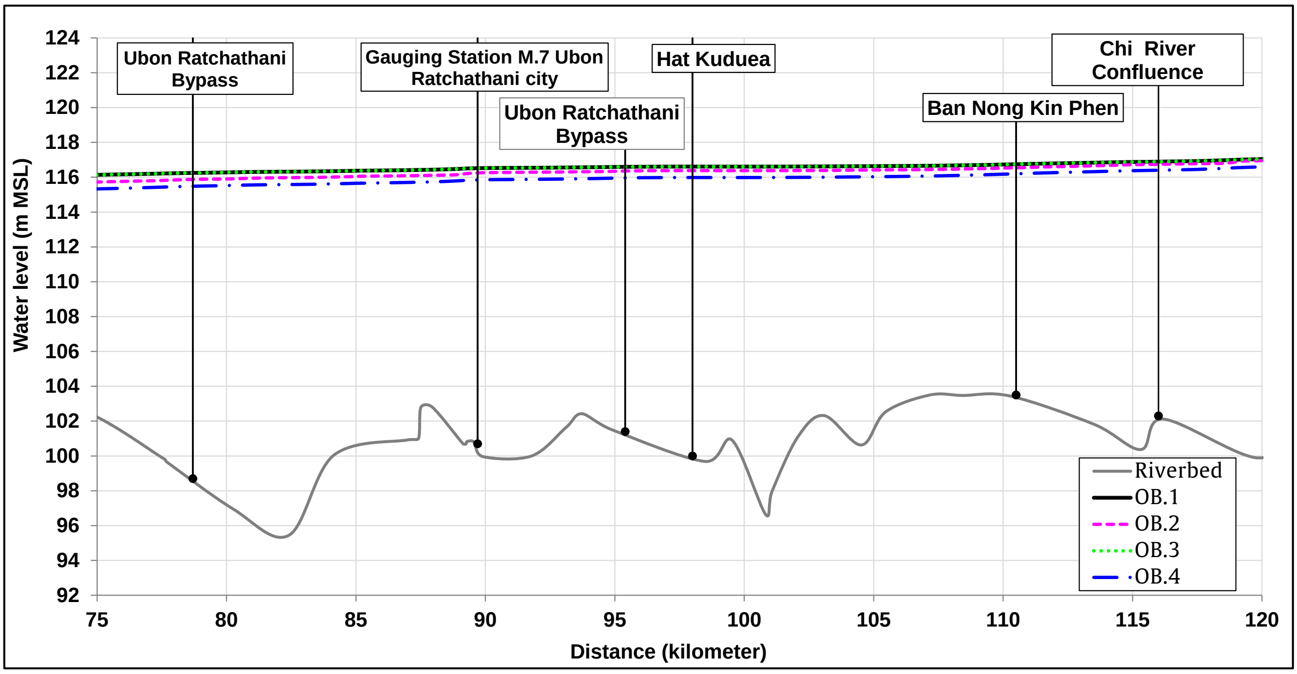

Figure 14 Simulated water levels in the Mun River under various cases (A focus on Ubon Ratchathani City).

2.1 With Kaeng Saphue and Pak Mun Dam (OB.1): This case, representing the current condition, yielded the highest water level at 116.50 m MSL. The flooded area from the overflowing Mun River in Ubon Ratchathani Province was 483.58 sq.km., with a flood duration of 75 days.

2.2 Without Kaeng Saphue (OB.2): Removing Kaeng Saphue resulted in a peak water level of 116.15 m MSL at station M.7. The flooded area decreased to 463.07 sq.km. with a flood duration of 64 days.

2.3 Without Pak Mun Dam (OB.3): This case, surprisingly, showed the same peak water level at station M.7 as the current condition (116.50 m MSL). The flooded area decreased to 483.58 sq.km. with a flood duration of 75 days.

2.4 Without both Kaeng Saphue and Pak Mun Dam (OB.4): The case without both obstructions yielded the lowest peak water level at station M.7, recorded at 115.92 m MSL. The flooded area decreased to 445.06 sq.km. with a flood duration of 60 days.

The water levels at station M.7 for all four study cases are presented in Figure 15, while the corresponding flooded areas are detailed in Table 3. The study results revealed that both the current condition (OB.1), which includes Kaeng Saphue and the Pak Mun Dam, and the case without the Pak Mun Dam (OB.3) resulted in the same peak water level of 116.50 m MSL at station M.7.

In the case without Kaeng Saphue (OB.2), the water level at station M.7 was reduced to 116.15 m MSL (a reduction of 0.35 meters). When both the Pak

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Mun Dam and Kaeng Saphue were removed (OB.4), the water level at gauging station M.7 further decreased to 115.92 m MSL (a reduction of 0.58 meters). These findings align with previous studies on flood prevention in the lower Mun River basin, which indicate that improving rapids can effectively reduce water levels [11, 13].

The study's findings indicate that Kaeng Saphue is currently the primary obstruction to flow. Specifically, the presence of Kaeng Saphue consistently caused water levels to rise. Conversely, the absence of the Pak Mun Dam alone did not significantly impact the water level when Kaeng Saphue was present. However, if Kaeng Saphue was removed while the Pak Mun Dam remained, the water level still rose when compared to the scenario where both were absent. This further reinforces Kaeng Saphue's dominant role. Regarding the Pak Mun Dam, which is situated downstream of Kaeng Saphue, its riverbed level is approximately 12.0 meters lower, and its highest water level is about 3.0 meters lower than the riverbed level at Kaeng Saphue. Critically, no backwater effect from the Pak Mun Dam was observed upstream, confirming that the Pak Mun Dam has no impact on the current flood level.

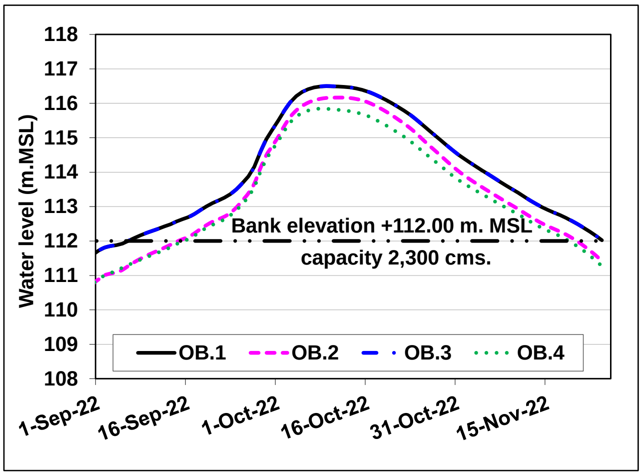

Figure 15 Water Levels at Gauging Station M.7 for Each Case.

Table 3 Effects of flow obstructions on flooding in the 2022 simulation.

Case study	Peak discharge (m^3/s)	Peak water level (m MSL)	Duration of flooding (days)	Flooded area extent (km^2)
OB.1	6,166	116.50	75	483.58
(Present)				
OB.2	6,166	116.15	67	463.07
Percent (%)		(-0.30%)	(-10.67%)	(-4.24%)
OB.3	6,166	116.50	75	483.58
Percent (%)		(0.00%)	(0.00%)	(0.00%)
OB.4	6,166	115.92	60	445.06
Percent (%)		(-0.50%)	(-20.00%)	(-7.97%)

Despite the removal of flow obstructions, the model indicated that overflow and flooding persisted in the area. This is because the volume of floodwater still exceeded the river's capacity. Therefore, improving only Kaeng Saphue would not fully resolve the flooding issue. This observation is consistent with prior research [10], which found that while removing obstructions like weirs and culverts reduced flood length and levels, it did not eliminate flooding entirely.

CONCLUSIONS

Flooding affects the Mun River Basin due to a combination of contributing factors. This study focuses on analyzing the impact of hydraulic obstructions on the severe flooding event in 2022, which was the most significant after the historical flood of 1978. The results indicate that although flow obstructions such as Kaeng Saphue and the Pak Mun Dam are not the primary causes of flooding, excessive rainfall exceeding the river's capacity remains the dominant factor. Nonetheless, these obstructions play a role in impeding the drainage of water into the Mekong River, leading to elevated flood levels, expanded inundation areas, and prolonged flood durations.

The downstream section of the Mun River in Phibun Mangsahan District exhibits an uneven riverbed topography, characterized by numerous potholes and rapids. This irregular geomorphology increases the roughness coefficient compared to rivers with uniform slopes, thereby reducing water flow velocity and efficiency. Therefore, any improvements or dredging activities on the downstream Mun River should ideally extend along the entire river segment, reaching its confluence with the Mekong River to effectively mitigate flooding.

However, such interventions often face environmental constraints, particularly regarding their impact on local livelihoods and traditional fishing practices. The Mun River's diverse physical characteristics contribute significantly to the rich

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biodiversity of fish species in the region. Moreover, Kaeng Saphue remains an important tourist attraction in Phibun Mangsahan District, especially during April, when many visitors come for leisure and sightseeing. Therefore, this study proposes an approach that integrates engineering needs with the conservation of natural and social values. It emphasizes designing projects with ecological sensitivity; for example, the concept of improving the river channel without fully occupying the cross-section is an intriguing approach, but it must be implemented continuously along the entire river length to ensure uninterrupted flow. This approach also includes community and stakeholder participation, long-term monitoring and evaluation after construction, promotion of ecotourism, support for community economies related to biodiversity, and the establishment of joint committees involving government agencies, academic institutions, and local communities. Such collaboration will help ensure the long-term success of projects, reduce conflicts, and prevent post-implementation failures.

Regarding water resource management in the Mun River Basin and Ubon Ratchathani Province, relevant agencies have continuously addressed flood and drought challenges over time. While some issues have been resolved, many still require further attention. Flood mitigation efforts remain ongoing, with active community involvement and feedback.

Currently, the Office of the National Water Resources has developed a water chart for the Mun River Basin. This plan provides guidelines and recommendations for land use in flood-prone areas to avoid obstructing water flow. Significant flood mitigation projects include the Ubon Ratchathani Province Flood Prevention and Mitigation Project, as well as initiatives addressing flood and drought in the lower Chi-Sebai-Sebok and lower Mun River Basins. These projects involve constructing bypass channels around Yasothon and Ubon Ratchathani cities. Completed feasibility studies indicate a high readiness level for implementation. Once constructed, these projects are expected to protect Ubon Ratchathani city effectively from floods with a recurrence interval of 5 to 10 years.

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