

# Catastrophic Dam-Break Flood Modeling and Risk Assessment: A Case Study of Yongning Reservoir, China

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## Article

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Catastrophic Dam-Break Flood Modeling and Risk Assessment: A Case Study of Yongning Reservoir, China

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Abstract

Dam-break floods pose severe threats to downstream settlements and infrastructure, especially in narrow mountainous river valleys. In this study, the potential consequences of a hypothetical failure of Yongning Reservoir were assessed using the one-dimensional MIKE 11 hydrodynamic model under partial-breach and full-breach scenarios. Model verification was conducted at Xuyong hydrological station, where the simulated results showed good agreement with observed data. The results indicate that the full-breach scenario produces significantly greater flood hazards, with peak discharge increasing from 23,865 m³/s to 108,940 m³/s. Flood depth, velocity, and inundation extent were also substantially higher, while flood-wave arrival time was shorter, reducing evacuation time. These findings provide a scientific basis for dam-break risk assessment and emergency planning.

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**Keywords:** Dam-break flood, MIKE11 modeling, Yongning Reservoir, Hydrodynamic modeling, breach scenario, flood routing.

1. Introduction

Reservoir dams play an essential role in flood control, water supply, irrigation, and hydropower generation. However, dam failure can generate highly destructive flood waves that threaten downstream settlements, infrastructure, and river systems, especially in narrow mountainous valleys where flood routing is rapid and warning time is limited. Because of these risks, dam-break analysis has become an important component of reservoir safety assessment and emergency planning.[2,3,14]

Previous studies have shown that numerical hydrodynamic models are effective tools for simulating dam-break flood propagation and evaluating downstream hazard characteristics such as peak discharge, water level, flow velocity, travel time, and inundation extent[19,30]. In particular, one-dimensional unsteady-flow models such as MIKE 11 have been widely applied to riverine flood-routing problems because they can efficiently represent flood-wave propagation along complex channel networks and provide results that are directly relevant to downstream risk assessment. However, the severity of dam-break consequences depends strongly on breach conditions, reservoir storage, channel geometry, and downstream topography. Therefore, site-specific assessment is necessary for reservoirs located in steep and densely occupied river valleys[11,15].

Yongning Reservoir is a roller-compacted concrete (RCC) gravity dam located in the upper Yongning River basin, where downstream communities are distributed along a confined river corridor. In the event of dam failure, the released flood wave may rapidly propagate through key settlements such as Lianghe, Xuyong, Longfeng, Tianchi, Jiangmen, and Naxi, causing severe hydraulic

and socioeconomic impacts. Although a technical report has evaluated the dam-break flood process for this reservoir, the results have not yet been presented in a journal article form with a clear focus on model verification, downstream hydraulic response, and settlement exposure under different breach conditions[14].

Accordingly, this study investigates the downstream consequences of a hypothetical Yongning Reservoir dam break using the MIKE 11 one-dimensional hydrodynamic model. Two scenarios were considered, namely a half-breach scenario and a full-breach scenario. The model was first verified using the reported hydraulic condition at Xuyong hydrological station. It was then used to analyze breach outflow generation, downstream peak-discharge attenuation, maximum water level, flood depth, flow velocity, flood-wave arrival time, and inundation extent. The objective of this study is to provide a scientific basis for dam-break hazard assessment, emergency response planning, and flood-risk management in the Yongning River basin[8,9,10].

**2. Methods**

**2.1 Geographical and Hydrological Context**

The Yongning Reservoir (Figure 1) is located in the upper sections of the Qingshui River, a principal headwater tributary of the Yongning River in Xuyong County, Luzhou City. The dam is situated at the geographical coordinates 105°18‘54” " E and 28°06'57"" N, approximately 22 km （river distance） southwest of the metropolitan core of Xuyong County.



**Figure 1.** Yongning Reservoir Project Location Diagram.

The Yongning River is a first-order tributary that flows into the upper Yangtze River from its right bank. It drains an area of 3,228 km² and stretches 164 km long. The reservoir governs a catchment area of 167.4 km² at the dam location. The area has a humid subtropical monsoon climate, with an average annual precipitation of 1000 -1600 mm. Precipitation is markedly seasonal, with approximately 65.8% of the annual total occurring from May to September, resulting in a flood regime characterized by elevated peak discharges and short hydrograph rise-and-fall durations, particularly in steep, mountainous areas. Historical documentation and contemporary occurrences (e.g., 2015, 2016) have confirmed significant flood disasters in the watershed, underscoring the inherent susceptibility of downstream towns [1,12].

The Yongning Reservoir is a significant regional water infrastructure project classified as a large-scale (Type II) multi-purpose facility [16]. The principal functions include irrigation, water supply, and flood control for downstream Xuyong County and Lianghe Town along with supplementary hydropower generation. The primary dam is a 105-meter-high roller-compacted concrete gravity construction. The principal hydrological and engineering aspects of the reservoir are listed in Table 1.

Table 1. Input parameters of the Yongning Reservoir.

| Parameter                   | Value           | Unit   |
|-----------------------------|-----------------|--------|
| Catchment Area at Dam       | 167.4           | km²    |
| Total Storage Capacity      | 10,673          | 10⁴ m³ |
| Normal Pool Level           | 516.0           | m      |
| Dead Water Level            | 475.0           | m      |
| Flood Limit Level (May-Oct) | 513.5           | m      |
| Design Flood Level (P=1%)   | 517.0           | m      |
| Check Flood Level (P=0.1%)  | 517.67          | m      |
| Dam Type                    | RCC Gravity Dam |        |
| Maximum Dam Height          | 105             | m      |
| Crest Elevation             | 522.0           | m      |

2.2. Numerical Framework

The dam-break flood was investigated using a systematic scenario-driven hydrodynamic modeling framework [18,19]. The methodology consisted of four primary components: (1) definition of the breach scenarios, (2) development of the one-dimensional hydrodynamic model, (3) model execution and verification, and (4) post-processing for impact assessment. This approach provides a physics-based evaluation of the downstream hydraulic and inundation effects resulting from a hypothetical failure of Yongning Reservoir [30].

2.2.1 Dam-Break Scenario Definition and Breach Modeling

Two dam-break scenarios were considered in this study: a partial-breach scenario (S1) and a full-breach scenario (S2) [17,20]. In the half-breach scenario, the final breach bottom elevation was set to 470 m. In the full-breach scenario, the final breach bottom elevation was set to 427 m. For both scenarios, the final breach width was 33 m, the breach side slope was assumed to be vertical, and the breach development time was set to 1.0 h [20].

These breach parameters were adopted from the Yongning Reservoir dam-break technical report and were used to generate the breach outflow hydrographs for the MIKE 11 simulation. The two scenarios were defined to compare the influence of breach severity on downstream flood propagation, hydraulic intensity, and settlement exposure [29]. To maintain consistency, the scenarios are referred to throughout this paper only as half breach and full breach. The geometric configuration of the two breach scenarios is presented in Figure 2.

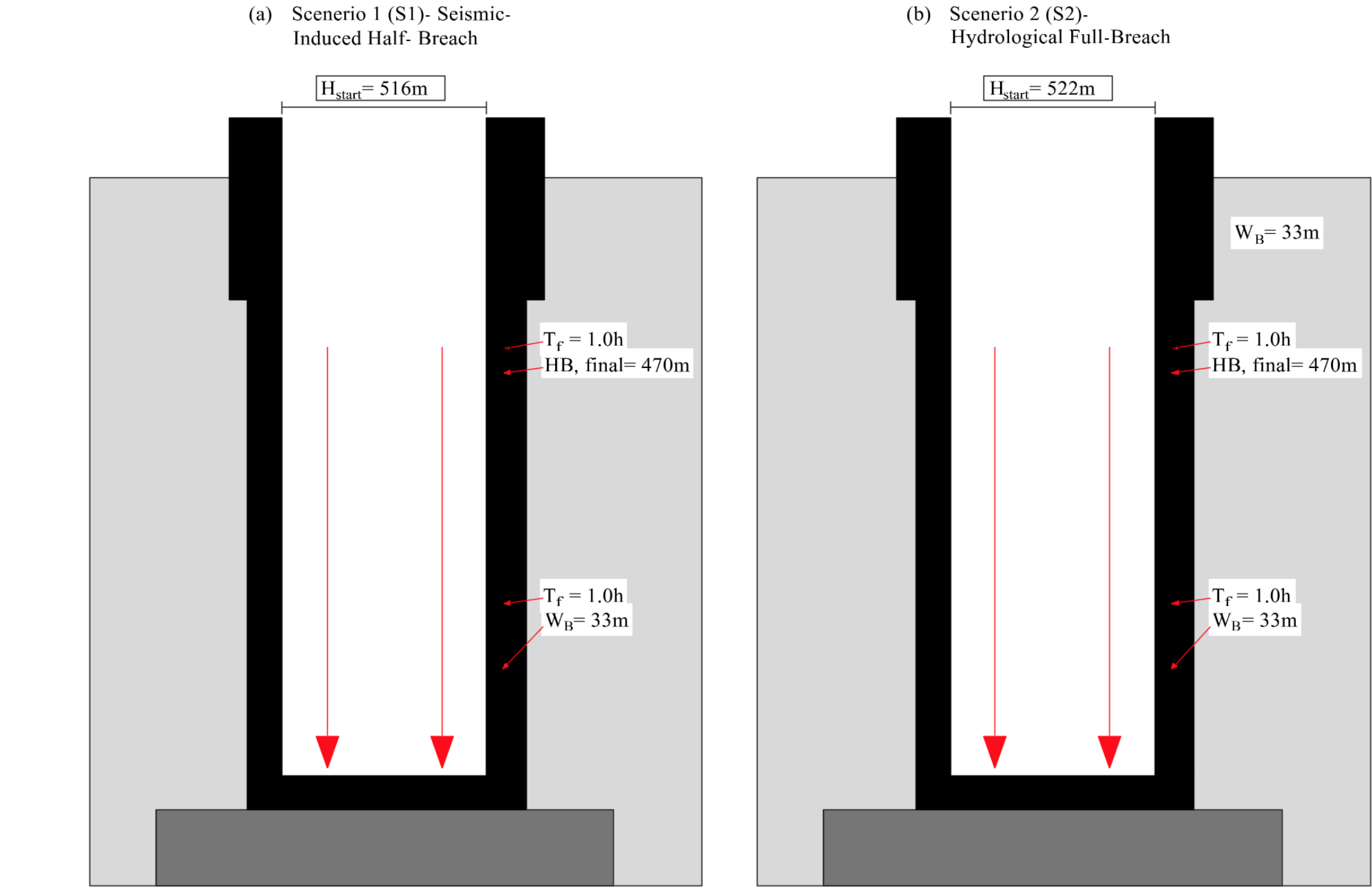


**Figure 2.** Conceptual representation of the breach geometry for the two failure scenarios. (a) Scenario S1(half-breach): Triggered by 2000- year return flood and seismic activity, with an initial water level of 516m and a final breach bottom of 470m. (b) Scenario S2 (full breach), triggered by 1000- year return flood overtopping condition at dam crest level (initial reservoir level = 522 m; final breach invert = 427 m). For both scenarios, the breach bottom width is  $W_b = 33$  m, side slope is 0H:1V (vertical), and breach formation time is  $T_f = 1.0$  h

The discharge through the developing breach was determined using the broad-crested weir equation. The equation incorporates both flows through the breach opening and the overtopping flow across the remaining dam crest. The geometric and temporal parameters of each breach scenario are listed in Table 2.

73 Table 2. Dam breach parameters for the two failure scenarios.

74

75

| Parameter                     | Scenario 1 (S1): Partial Half-Breach      | Scenario 2 (S2): Full-Breach                    | Unit |
|-------------------------------|-------------------------------------------|-------------------------------------------------|------|
| Triggering Mechanism          | 2000-yr Flood + Seismic Event             | 1000-yr Super-Standard Flood                    | -    |
| Triggering Water Level        | Normal Pool Level (516.0)                 | Dam Crest Level (522.0)                         | m    |
| Breach Type                   | Sudden Partial Breach                     | Sudden Complete Breach                          | -    |
| Final Breach Bottom Elevation | 470.0                                     | 427.0                                           | m    |
| Final Breach Bottom Width     | 33                                        | 33                                              | m    |
| Final Breach Depth            | 46                                        | 95                                              | m    |
| Breach Side Slope (H: V)      | 1:0 (Vertical)                            | 1:0 (Vertical)                                  | -    |
| Breach Development Time       | 1.0                                       | 1.0                                             | hour |
| Upstream Inflow Hydrograph    | 2000-Year Design Flood (Peak: 2210 (m³/s) | 1000-Year Design Flood (Peak: 2,210 2010 (m³/s) | -    |

76 **2.2.2 Governing equations and model setup**

77 The dam-break flood-routing simulation was carried out using the one-dimensional MIKE 11 hydrodynamic model implemented in MIKE 2023 [4,13,21]. The model solves the Saint-Venant  
78 equations for unsteady flow to simulate flood-wave propagation along the downstream river network [22,23]. The continuity equation is expressed as

79 **Continuity equation:**

80 
$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{1}$$

81 **Momentum equation:**

82 
$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + gA \frac{\partial h}{\partial x} + gAs_f \tag{2}$$

83

84 Where: x = longitudinal distance along the channel (m), t = time (s), Q = discharge (m³/s), A = cross-sectional flow area (m²), h = water depth (m), q = lateral inflow per unit length (m²/s), g =

gravitational acceleration (9.81 m/s<sup>2</sup>),  $S_f$  = friction slope.

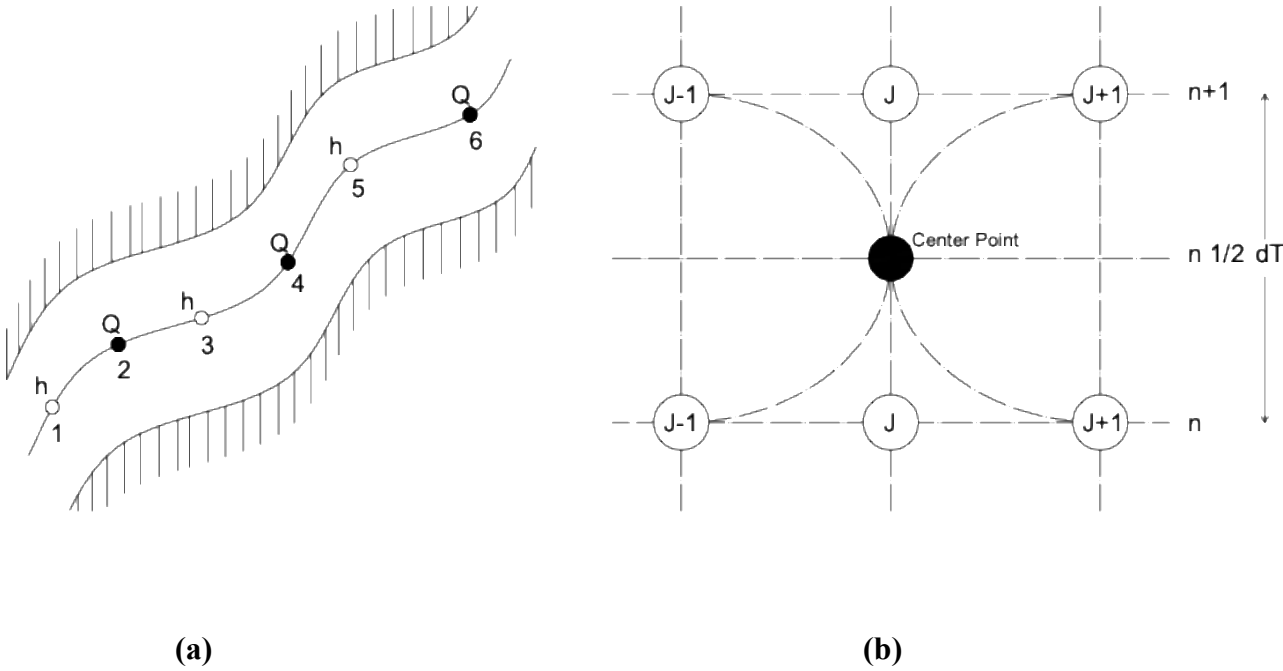
The friction slope,  $S_f$ , was calculated using semi-empirical Manning's equation, which was applied to every cross-section in the model [5]:

$$S_f = \frac{n^2 Q |Q|}{A^2 R^{4/3}} \tag{3}$$

Equation (3) gives the friction slope  $S_f$  according to Manning's equation, where  $n$  is Manning's roughness coefficient,  $Q$  is discharge,  $A$  is the cross-sectional area, and  $R$  is the hydraulic radius.

This term represents the energy loss due to channel resistance [26].

The MIKE 11 model was established using the standard input structure, including the river-network, cross-section, boundary-condition, hydrodynamic parameter, and simulation control files, as illustrated in Figure 3 [4]. The river-network file defines the branch layout, projected coordinates, and chainage-based longitudinal discretization of the computational domain, whereas the cross-section file provides the elevation profiles and processed hydraulic geometry of each section. Together, these files define both the topological structure and the hydraulic representation of the modeled river network [24, 25].



**Note. Adapted from (Abbott & Ionescu, 1967; DHI, 2022).**

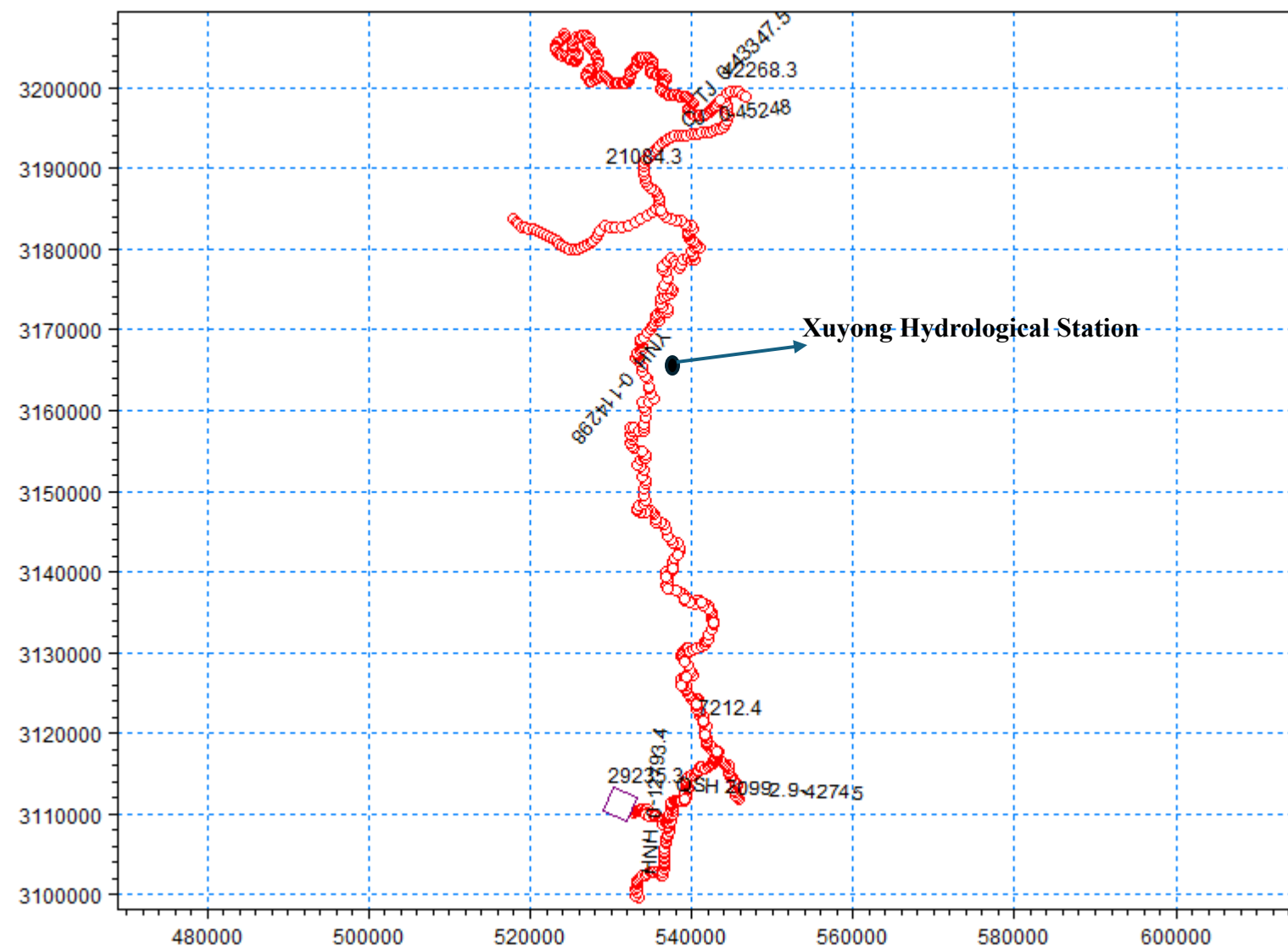
**Figure 3. Abbott scheme water level and discharge point alternating layout diagram.**

### 2.2.3 River network and hydraulic parameters

The computational domain was established using the standard MIKE 11 input files, including the river-network, cross-section, boundary-condition, hydrodynamic parameter, and simulation-control files. As shown in Figure 4, the model consists of five branches, namely QSH, HNH, YNH, CJ, and TJ, with a total of 572 cross-sections and a combined river-network length of approximately 237.19 km. The cross-sections were used to define the hydraulic geometry of the modeled river system and to represent the relationships among water level, flow area, hydraulic radius, and channel width along the downstream reaches.

Flow resistance was represented using Manning's roughness formulation with the Uniform Section approach in MIKE 11. A global resistance value of 0.04 was specified, while local branch-wise Manning's roughness coefficients were assigned as 0.042 for QSH, HNH, and YNH, 0.035 for CJ, and 0.036 for TJ. These values were used to characterize the hydraulic resistance of the

106 different river branches during unsteady flood routing.  
 107



108  
 109  
 110  
 111 **Figure 4.** River network, cross-section distribution, major downstream settlements, and the location of Xuyong Hydrological Station used for model verification.  
 112

#### 113 2.2.4 Boundary Conditions and Simulation Parameters

114 The upstream boundary condition was defined using the inflow hydrographs shown in Figure 5 and applied through the Q.dfs0 file. In the present manuscript, Scenario S1 has a peak inflow of  
 115  $2210 \text{ m}^3 \text{ s}^{-1}$ , whereas Scenario S2 has a peak inflow of  $2010 \text{ m}^3 \text{ s}^{-1}$ . The downstream boundary was specified as a water-level control condition. All simulations were performed from 2022-01-  
 116 01 01:00:00 to 2022-01-01 22:00:00 with a fixed time step of 1 s.

117  
 118 Model verification was conducted using the reported hydraulic condition at Xuyong hydrological station. The MIKE 11 outputs were then used to extract peak discharge, maximum water  
 119 level, flood depth, flow velocity, flood-wave arrival time, inundation extent, and land-use exposure under the two dam-break scenarios [27,28].

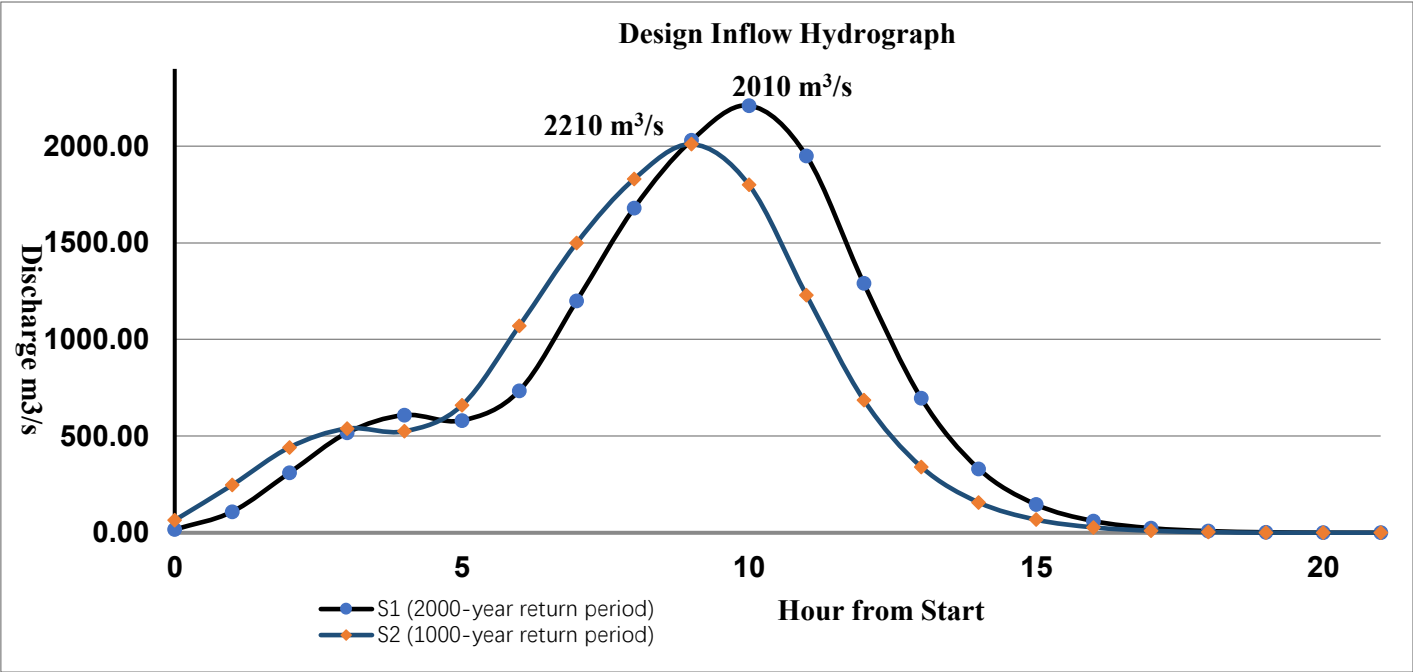


**Figure 5.** Design inflow hydrographs used as upstream boundary conditions for Scenario S1 (flood with a 2000-year return period) and Scenario S2 (flood with a 1000-year return period).

**3. Results and Discussion**

**3.1 Model verification at Xuyong hydrological station**

Xuyong hydrological station was used as the main reference point to assess model reliability. According to the project report, the observed flood condition at Xuyong corresponded to a discharge of 2200 m³/s and a water level of 336.18 m. The closest simulated point from the selected Yongning River control section occurred at 2022-01-01 14:10:00, with a discharge of 2214.901 m³/s and a water level of 336.344 m. The differences were only 14.901 m³/s for discharge and 0.164 m for water level, indicating very close agreement between the observed and simulated hydraulic states.

As shown in Figure 6, the graph presents the simulated stage-discharge trajectory together with the reported observed checkpoint at Xuyong hydrological station. The observed point is located almost directly on the simulated curve, showing that the relationship between flow discharge and water level produced by the model is highly consistent with the reported field condition at Xuyong. This close correspondence confirms that the model can reasonably reproduce the hydraulic behavior at this key downstream control location and is therefore suitable for the subsequent dam-break simulation analysis [18,19].

After verifying the hydraulic reasonableness of the model at Xuyong hydrological station, the dam-break simulation results were analyzed in terms of breach outflow generation, downstream flood routing, hydraulic intensity, and inundation impacts.

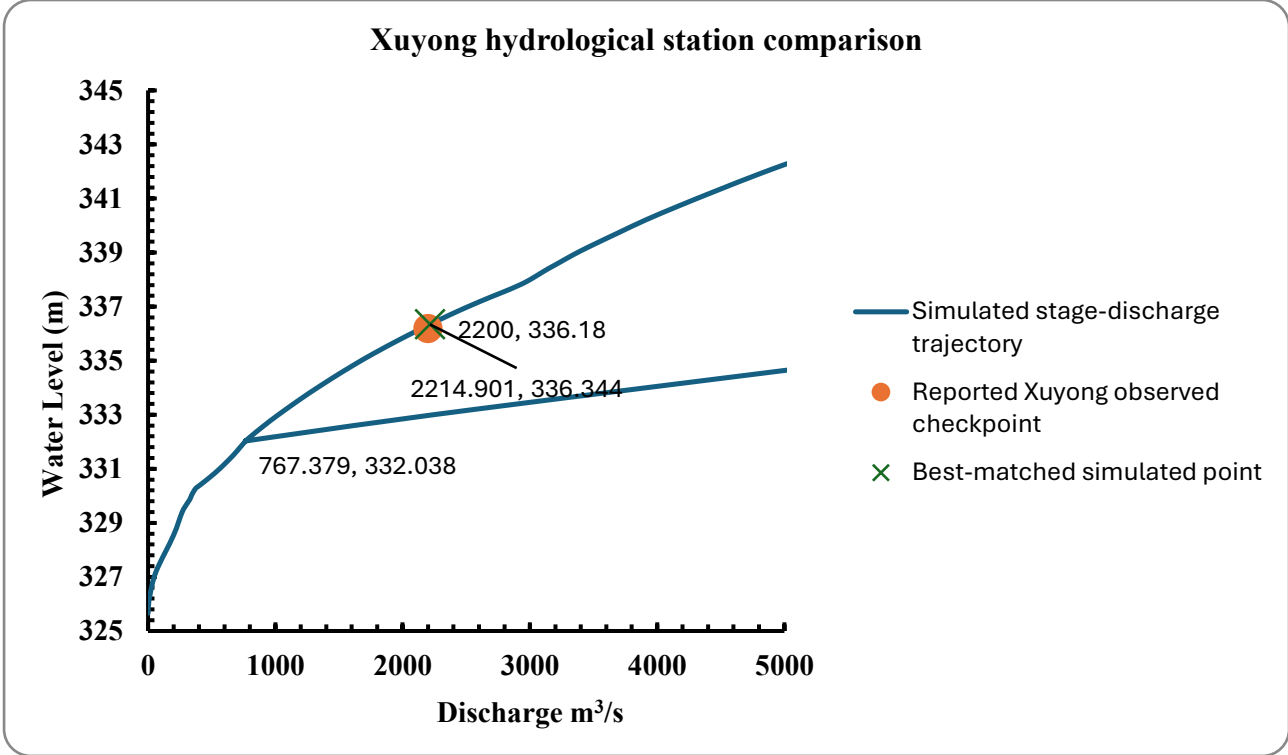


**Figure 6.** Comparison between the reported observed hydraulic checkpoint at Xuyong hydrological station and the simulated stage-discharge trajectory at the best-matched control section on the Yongning River main branch. The simulated point nearest to the observed Xuyong checkpoint shows close agreement in both discharge and water level.

### 3.2 Breach outflow hydrographs and downstream peak-discharge attenuation

The two failure modes produced very different flood magnitudes. In the half-breach scenario, the peak outflow at the dam site reached  $23,865 \text{ m}^3/\text{s}$ , whereas in the full-breach scenario it increased sharply to  $108,940 \text{ m}^3/\text{s}$ . This indicates that complete breach development would generate a much more destructive flood wave immediately downstream of the reservoir.

As shown in Figure 7, peak discharge decreased continuously with downstream distance in both scenarios. In the partial half-breach case, the flood peak attenuated from  $23,865 \text{ m}^3/\text{s}$  at the dam site to  $4,686 \text{ m}^3/\text{s}$  at the Yongning River outlet. In the full-breach case, it decreased from  $108,940 \text{ m}^3/\text{s}$  to  $9,241 \text{ m}^3/\text{s}$  over the same reach. The figure clearly shows that the attenuation was strongest in the upper and middle reaches, while the full-breach scenario maintained much higher discharge values throughout the downstream river network.

These results confirm that downstream flood hazard is highly sensitive to breach extent. Although the flood wave weakened during downstream routing, the residual discharge remained severe, particularly under full-breach conditions. Therefore, the full-breach scenario was identified as the governing hydraulic condition for the subsequent analysis of flood depth, velocity, arrival time, and inundation extent [30].

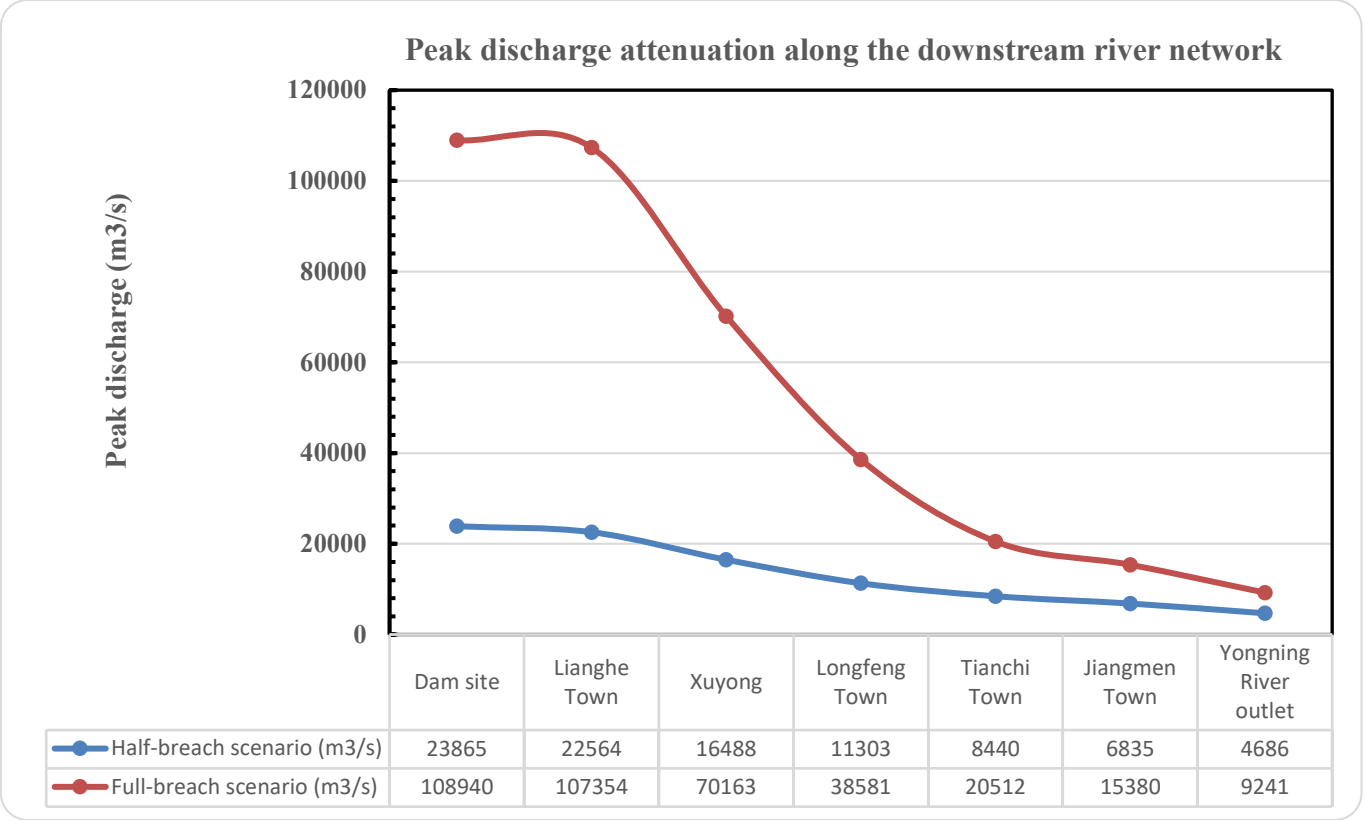


Figure 7. Peak discharge attenuation along the downstream river network under the half-breach and full-breach scenarios.

3.3 Maximum water level and flow depth at representative downstream sections

The simulated maximum water level and flow depth indicate severe flooding along the downstream river corridor. In the half-breach scenario, maximum water levels at Lianghe Town, Xuyong, Longfeng Town, Tianchi Town, Jiangmen Town, and Naxi District reached 399.80 m, 356.50 m, 338.02 m, 311.66 m, 284.88 m, and 247.37 m, respectively, with corresponding maximum depths of 19.76 m, 20.57 m, 16.02 m, 20.44 m, 22.45 m, and 18.78 m.

In the full-breach scenario, the maximum water levels increased to 419.63 m, 375.09 m, 349.22 m, 321.10 m, 293.66 m, and 249.79 m, while the corresponding maximum depths increased to 39.59 m, 39.15 m, 27.22 m, 29.88 m, 31.23 m, and 21.21 m, respectively.

As shown in Figure 8, the full-breach scenario produced consistently higher maximum water levels than the partial half-breach scenario at all representative sections. The largest differences occurred at Lianghe Town and Xuyong, indicating that the upper and middle reaches are the most hydraulically vulnerable to catastrophic dam failure [2].

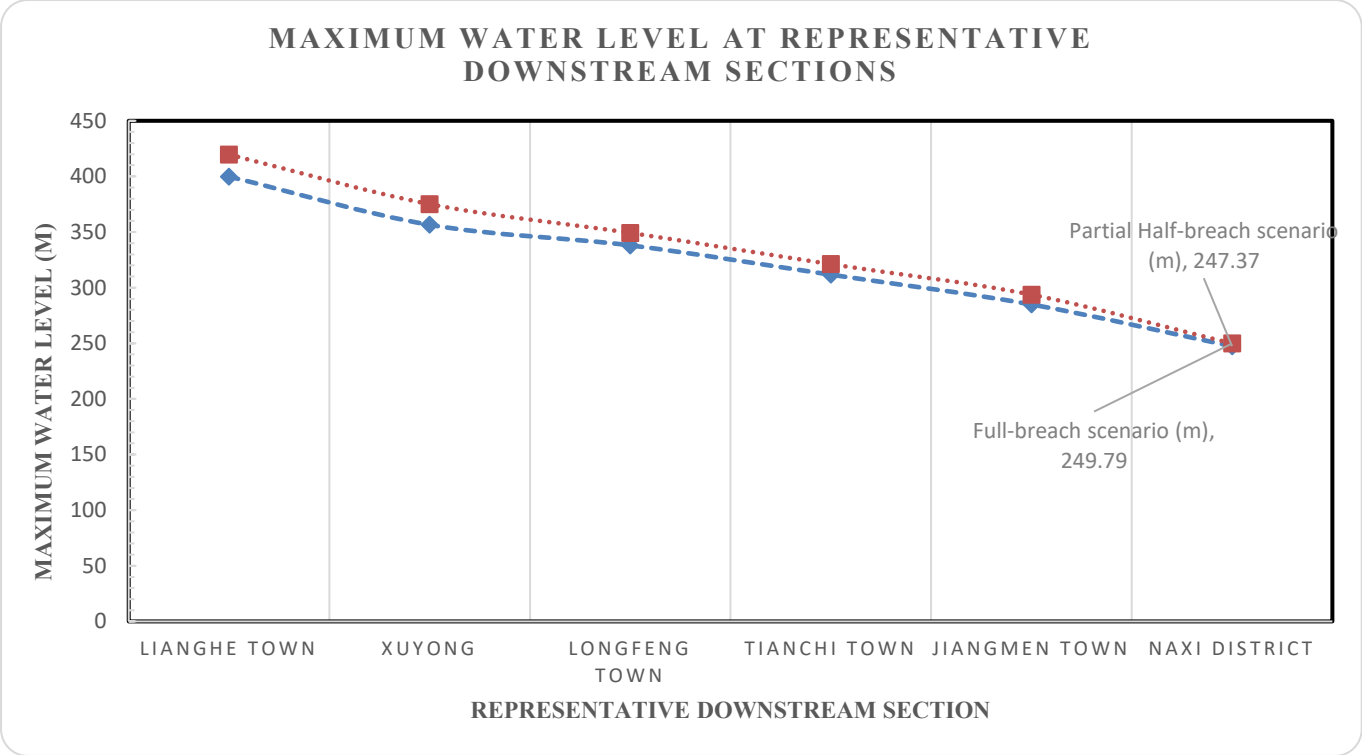


**Figure 8.** Maximum water level at representative downstream sections under the half-breach and full-breach scenarios.

### 3.4 Maximum flow velocity along the downstream river network

The simulated maximum flow velocity indicates strong flood impact along the downstream river network [27]. In the half-breach scenario, the maximum velocity reached 8.31 m/s near the dam and gradually decreased to 2.78 m/s downstream. In the full-breach scenario, the maximum velocity increased to 8.97 m/s and remained above 8.0 m/s in the upper 25 km of the river.

As shown in Figure 9, the full-breach scenario produced consistently higher velocities than the half-breach scenario along the entire downstream reach. The highest velocities occurred in the upper and middle reaches, where the flood wave had the greatest erosive and destructive potential. These results indicate that the full-breach scenario would generate stronger hydraulic forces and greater risk of structural damage and channel erosion.

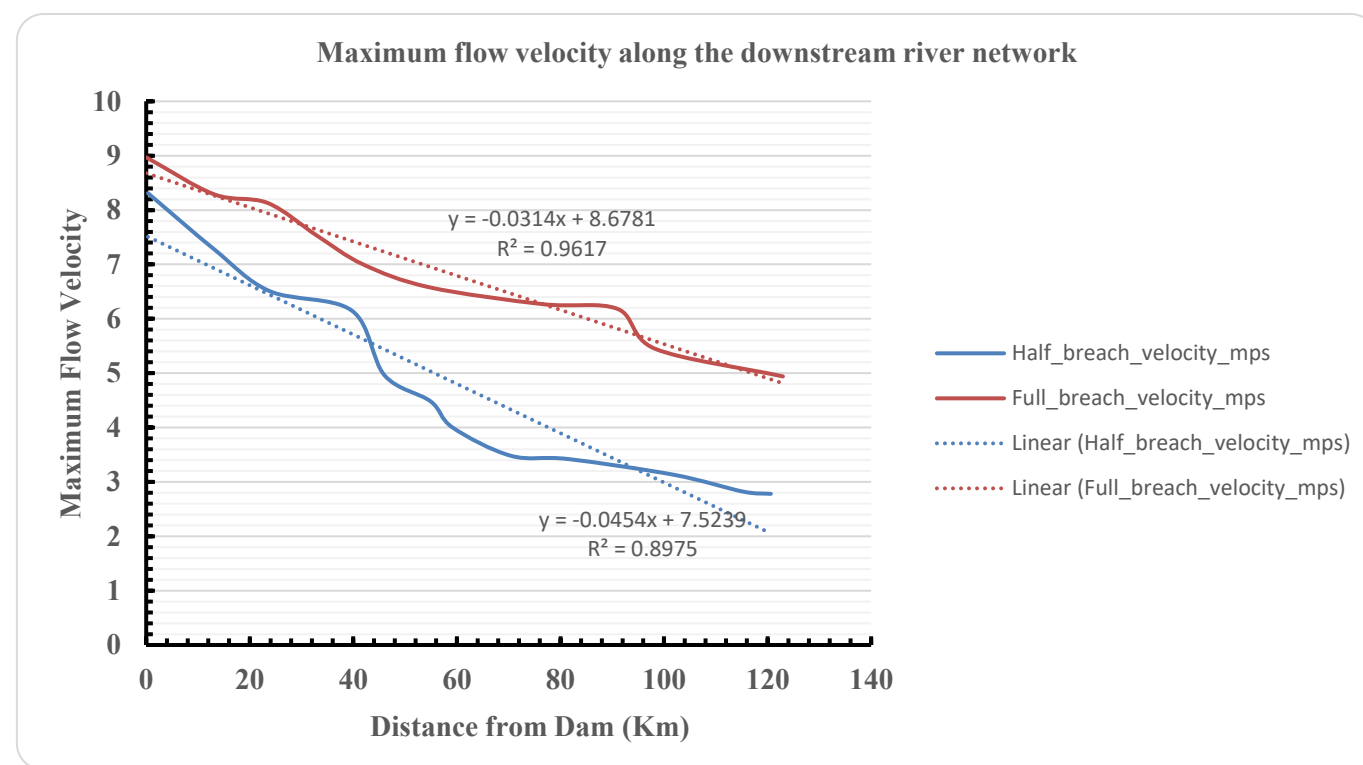


**Figure 9.** Maximum flow velocity along the downstream river network under the half-breach and full-breach scenarios.

### 3.5 Flood-wave arrival time at key downstream settlements

The simulated flood-wave arrival time indicates very limited warning time for the downstream settlements. In the half-breach scenario, the flood peak reached Lianghe Town in 1 h 5 min, Xuyong in 1 h 35 min, Longfeng Town in 2 h 5 min, Tianchi Town in 3 h 20 min, Jiangmen Town in 4 h 40 min, Tianxian Town in 8 h 45 min, and Naxi District in 9 h 15 min. In the full-breach scenario, the flood wave arrived faster, reaching Lianghe Town in 1 h, Xuyong in 1 h 20 min, Longfeng Town in 1 h 35 min, Tianchi Town in 2 h 30 min, Jiangmen Town in 3 h 30 min, Tianxian Town in 6 h 20 min, and Naxi District in 6 h 55 min.

As shown in Figure 10, the full-breach scenario consistently produced shorter arrival times than the partial half-breach scenario along the entire downstream river network. The shortest response time occurred at Lianghe Town and Xuyong, indicating that the upper and middle reaches are the most critical areas for emergency warning and evacuation.

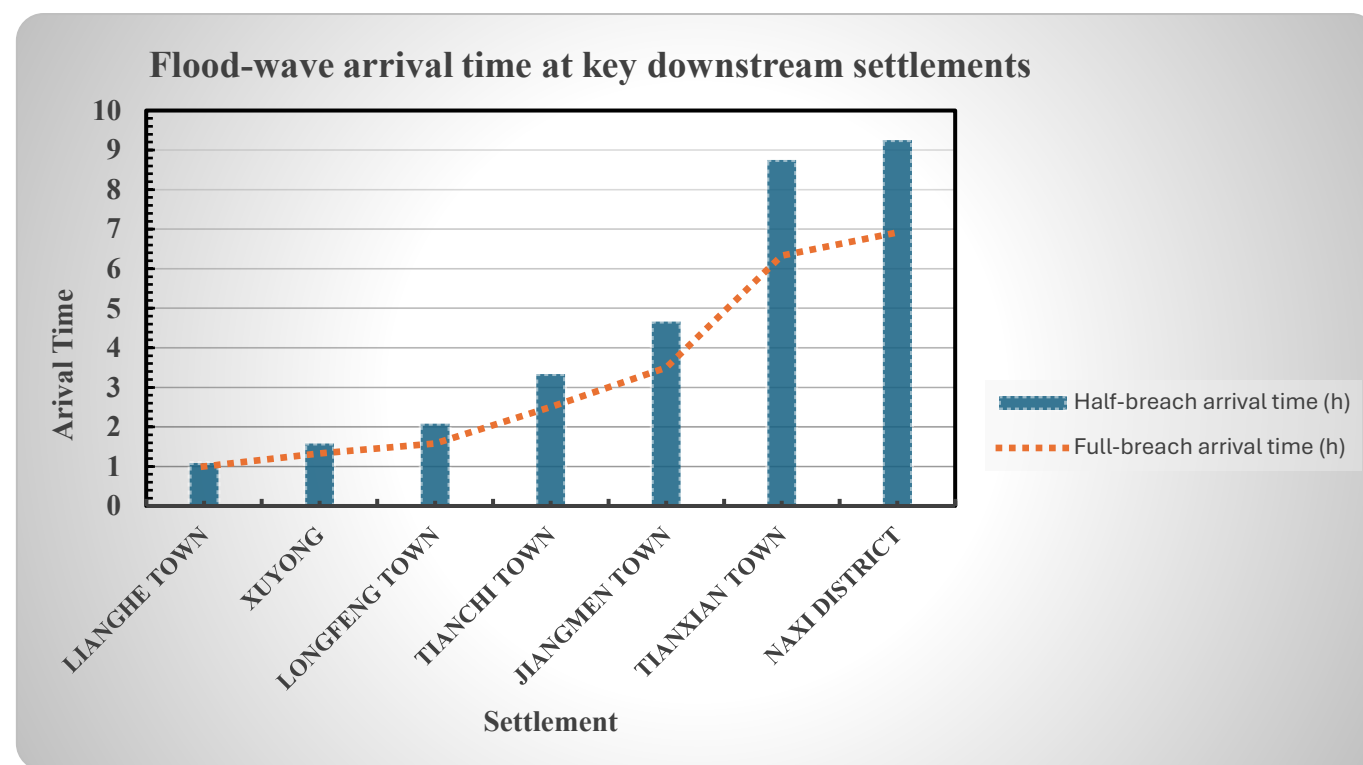


**Figure 10.** Flood-wave arrival time at key downstream settlements under the half-breach and full-breach scenarios.

### 3.6 Inundation extent and impacts on settlements

The inundation results show that the full-breach scenario produced much larger affected areas than the half-breach scenario throughout the downstream settlement system. Xuyong was the most severely affected major settlement, where the inundated urban residential area increased from 1.081 km<sup>2</sup> to 1.703 km<sup>2</sup>, the urban-village area increased from 1.512 km<sup>2</sup> to 2.289 km<sup>2</sup>, and the maximum urban inundation depth increased from 12.83 m to 24.14 m.

At the town scale, the affected areas also increased markedly under the full-breach scenario. For example, the inundated residential area increased from 0.0662 km<sup>2</sup> to 0.0986 km<sup>2</sup> in Lianghe, from 0.0579 km<sup>2</sup> to 0.0812 km<sup>2</sup> in Longfeng, from 0.0571 km<sup>2</sup> to 0.0676 km<sup>2</sup> in Tianchi, and from 0.1034 km<sup>2</sup> to 0.1681 km<sup>2</sup> in Jiangmen. In Naxi, the inundated urban residential area increased from 0.0719 km<sup>2</sup> to 0.1155 km<sup>2</sup>, while the urban-village area increased from 0.2158 km<sup>2</sup> to 0.5143 km<sup>2</sup>.

As shown in Figure 11, the full-breach scenario consistently produced larger affected residential and built-up areas than the partial half-breach scenario at all settlements. The figure clearly highlights Xuyong as the most severely inundated urban area and confirms that full breach would cause much greater damage to downstream residential land, town areas, and local infrastructure [3].

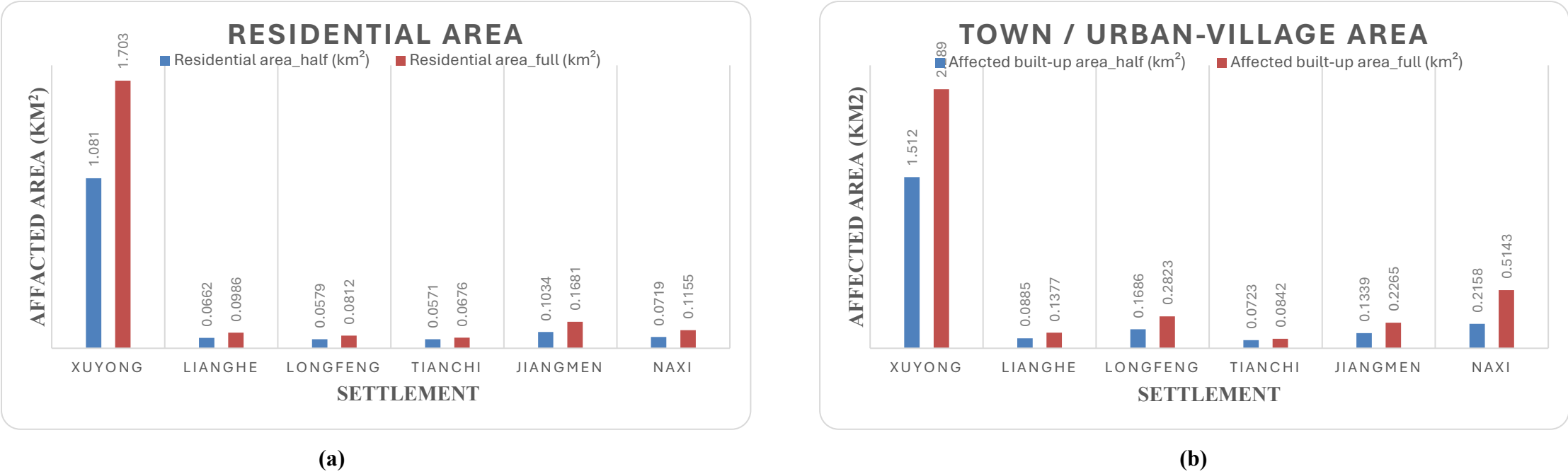


**Figure 11.** Inundation extent and affected settlement areas under the half-breach and full-breach scenarios.

**Conclusion**

This study evaluated the downstream consequences of a hypothetical failure of Yongning Reservoir using the MIKE 11 hydrodynamic model under half-breach and full-breach scenarios. The results show that breach severity has a decisive influence on downstream flood hazard. Compared with the partial-breach scenario, the full-breach scenario produced much larger peak breach discharge, higher downstream water levels and flood depths, greater flow velocity, and shorter flood-wave travel time.

The upper and middle downstream reaches, particularly Xuyong and Lianghe, were identified as the most hydraulically vulnerable areas because of their high-water levels, large flood depths, strong flow velocities, and limited warning time. The inundation analysis further showed that settlement exposure increased markedly under the full-breach scenario, with Xuyong being the most severely affected downstream urban area. These findings indicate that both hydraulic intensity and land-use exposure should be considered in downstream dam-break risk assessment.

Overall, the study demonstrates that a potential failure of Yongning Reservoir could cause severe downstream impacts, especially under full-breach conditions. The results provide a scientific basis for dam-break hazard assessment, emergency evacuation planning, and flood-risk management in the Yongning River basin [6,7].

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Software: Jeba Fariha Islam, DU Chenxi

Validation: Jeba Fariha Islam, WU Guanghui, DU Chenxi

Formal analysis: Jeba Fariha Islam, WU Guanghui

Investigation: Jeba Fariha Islam, DU Chenxi

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EDITOR COMMENT: Full manuscript requires detailed language polishing, improved discussion depth, and clearer novelty for SCI publication.