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Risk zoning of huge flood based on coupled hydrodynamic model

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Water for All
Harmony between Humans and Nature

第18届世界水资源大会
水与万物：
人与自然和谐共生

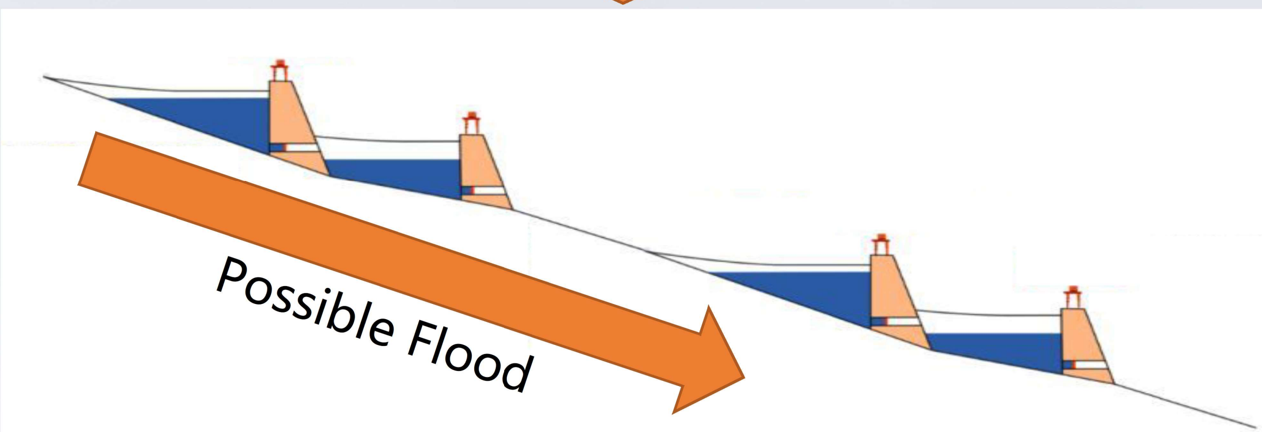
Content

- Introduction
- Study area and methodology
- Model construction
- Results and discussion
- Summarize

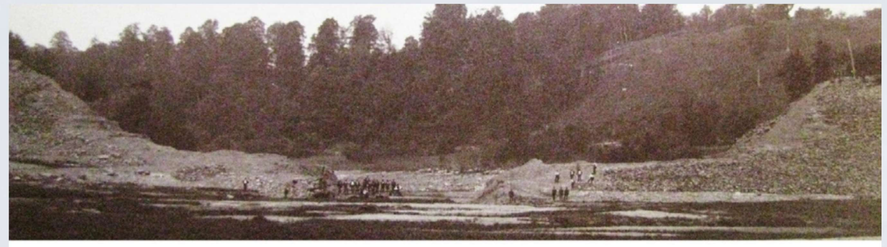
1 Introduction

Earthquake

Huge flood



Cascade reservoirs



The breach of South Fork dam

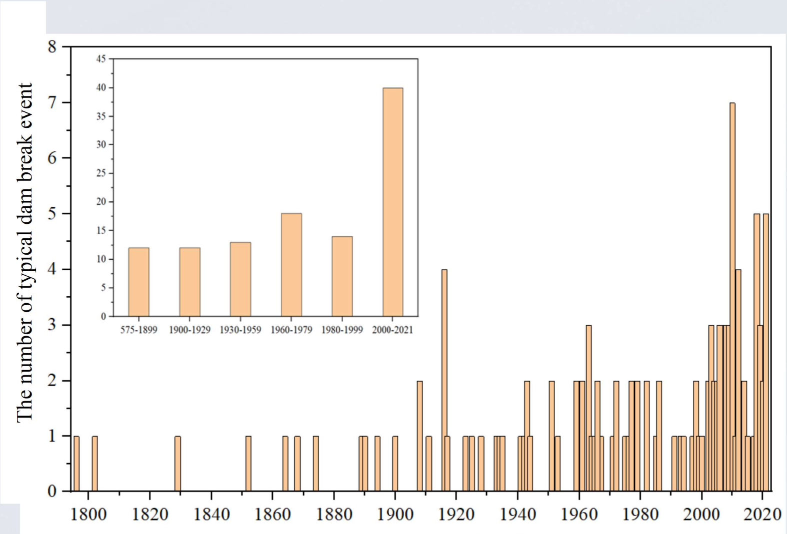
The breach of Kahovka dam

Large-scale earthquakes and **unusual floods** can cause the failure of dams, resulting in massive floods. This may trigger the **subsequent collapse of cascade reservoirs**.

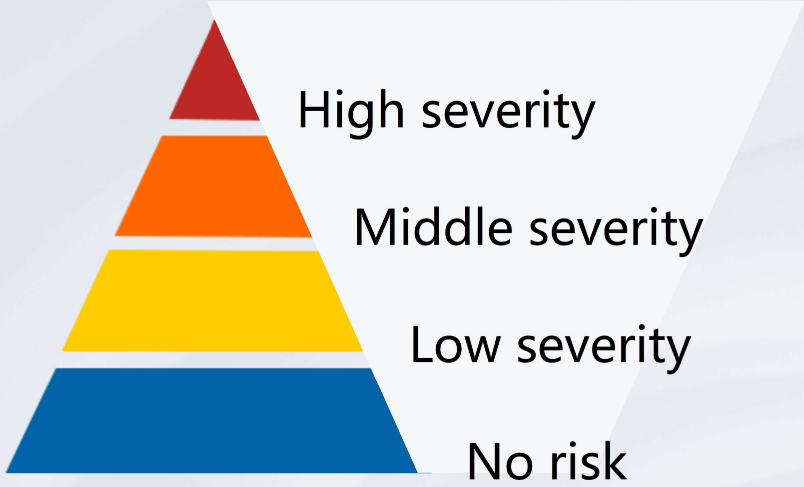
1 Introduction

Global warming

Extreme hydroclimatic



Typical Dam Break Event

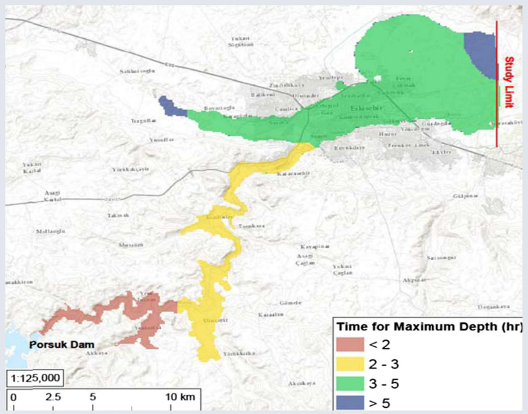


Risk classification

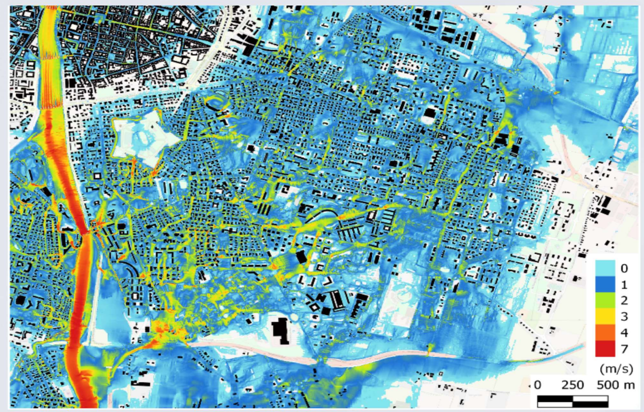
The global warming **amplified the hydroclimatic extremes** and **increased their frequency**. Furthermore, the typical dam break events increase, as time goes by since 1800. Therefore, the **risk zoning** of dam break floods has emerged as a challenging task for researchers.

1 Introduction

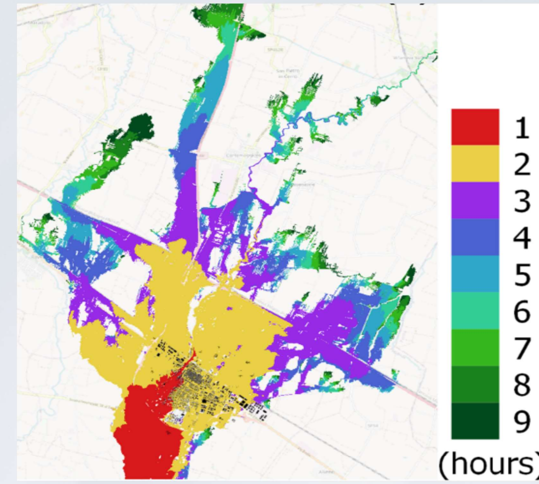
Risk zoning based on flood parameters



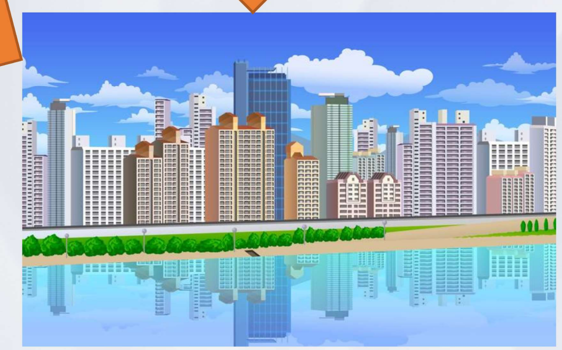
Water depth



Velocity



Flood arrival time


city

Those risk zoning methods based on flood parameters can **indicate the flood path**, they only **reveal its characteristics**, not **how it affects people and cities**.

What about the effects on people and cities?

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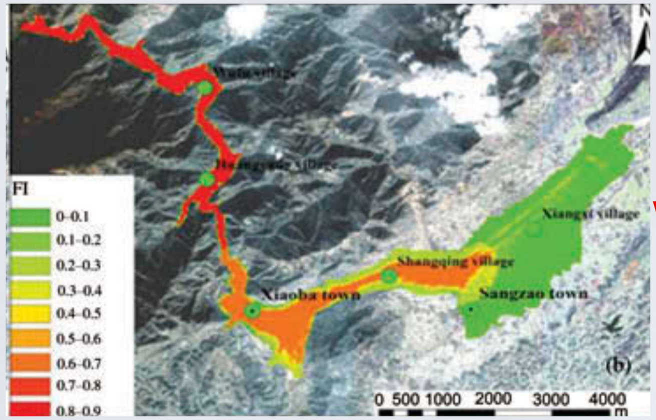
Risk zoning based on evaluation system

$$FI = 0.45WD + 0.22WR + 0.22V + 0.11D$$

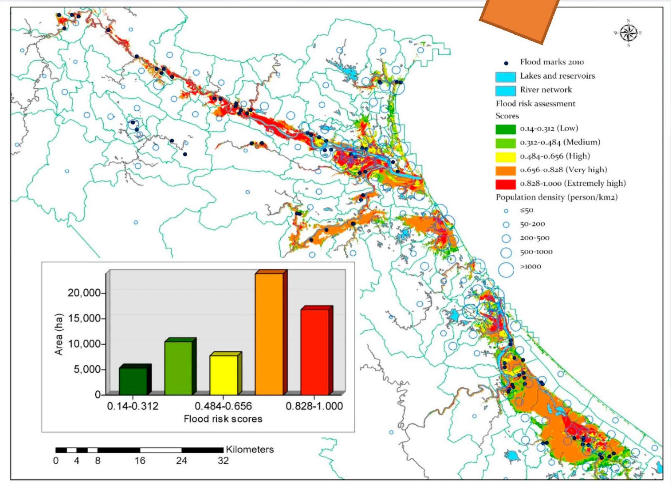
$$WD = 0.665 \times 10^{-3} e^{1.16h_{max}}$$

$$Disaster = PD \times FI$$



Flood-exposure index (FI)

What does he need to do?

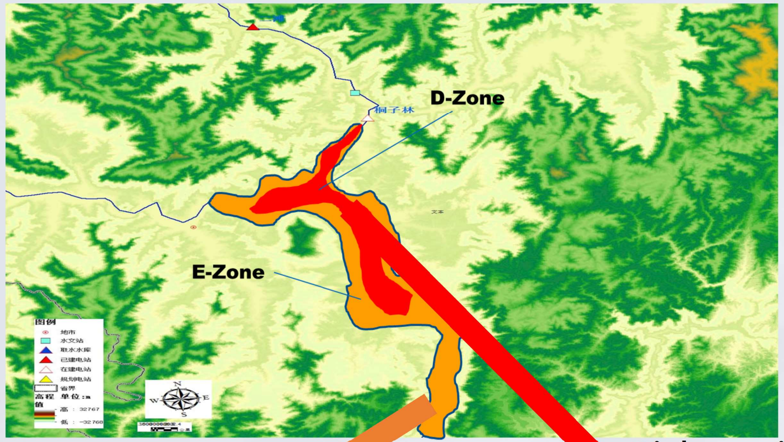


Spatial flood risk assessment

Those risk zoning methods based on evaluation system can indicate the **risk spatial distribution** and the risk level of whole flood, but don’ t consider the **personal evacuation** which considerably impacts risk zoning.

1 Introduction

Rescue operation



Risk zoning

The **life safety** in floods is the most important. So there need to be a risk zoning **considering personnel evacuation**. That could show who need to be evacuation and who need to find a emergency shelter.

Emergency transfer

Emergency shelter

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- **Study area and methodology**
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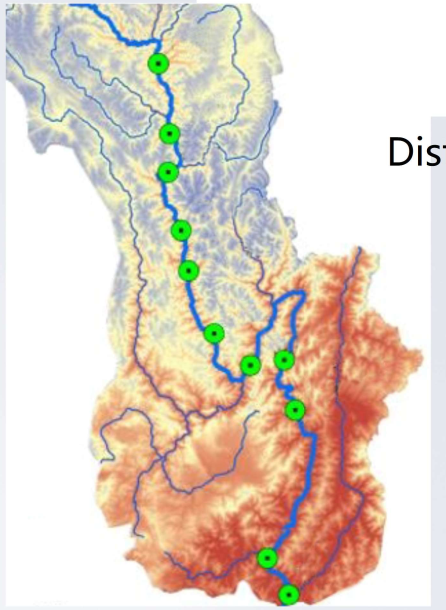
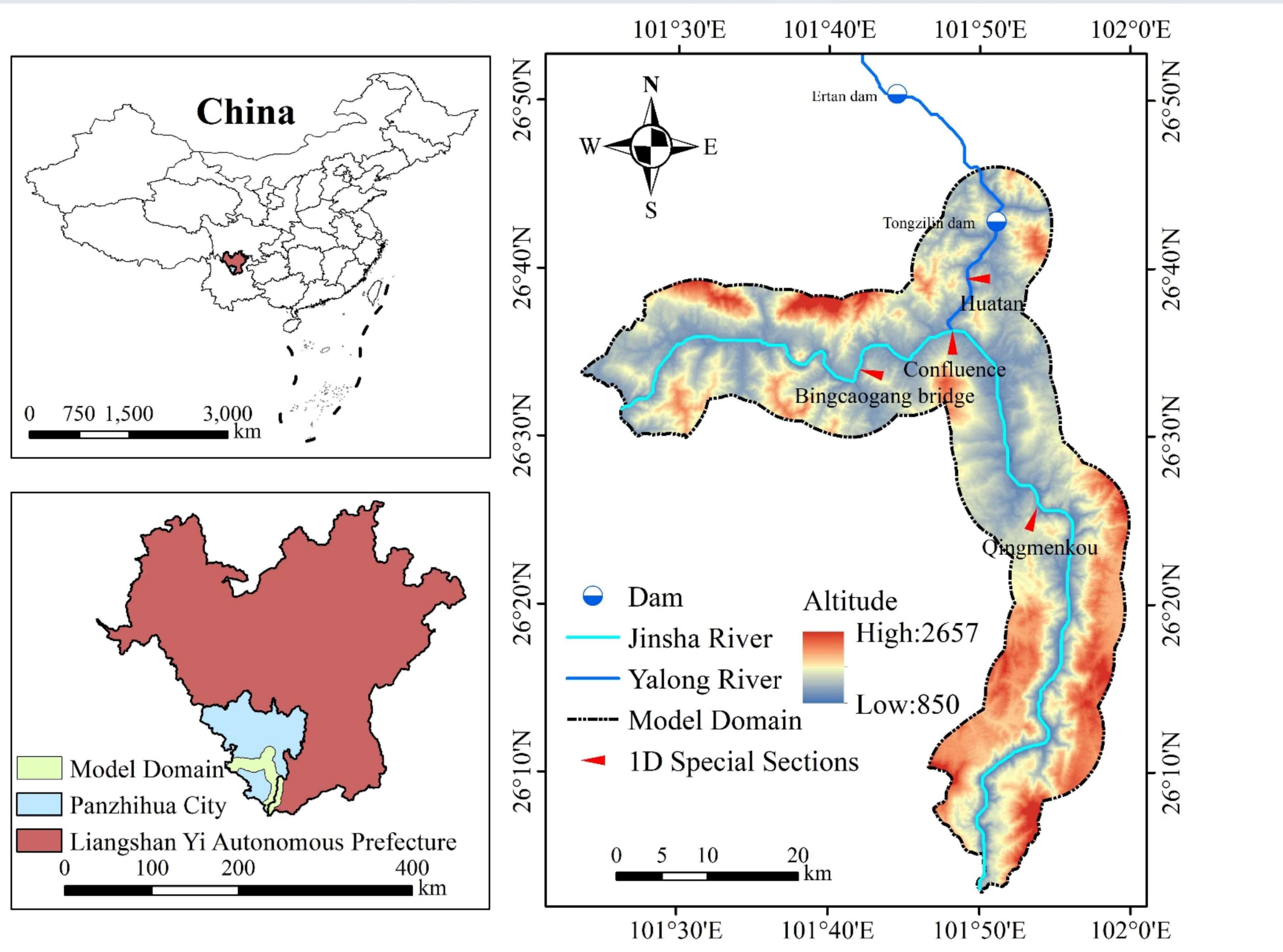
2.1 Study area

Distribution of hydropower energy in China



Cascade reservoirs of Yalong River

- Ertan:
  - Height: 240 meters
  - Total Water Capacity: 5.8 billion m³
- Tongzilin:
  - Height: 71.3 meters
  - Storage Capacity: 91.2 million m³

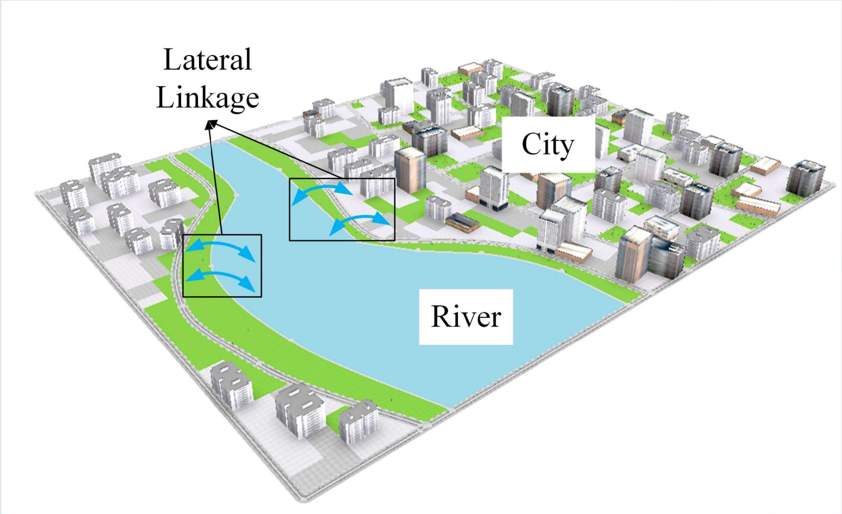


Study area

2.2 Coupled hydrodynamic model

□ coupled hydrodynamic model

Overflow



Lateral linkages

The lateral coupling model is employed to simulate the flood spread in **river** (1D model) and in **surface** (2D model). The exchange flow between 1D and 2D model is calculated by **weir equation**.

□ Governing equation

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=0$$

$$gA\left(\frac{\partial Z}{\partial x}+S_f\right)+\frac{\partial(Q^2/A)}{\partial x}+\frac{\partial Q}{\partial t}=0$$

$$\frac{\partial H}{\partial t}+\frac{\partial (Hu)}{\partial x}+\frac{\partial (Hv)}{\partial y}=S_{ce}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial z}{\partial x}+F_x+v_e(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2})$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial z}{\partial x}+F_y+v_e(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial x^2})$$

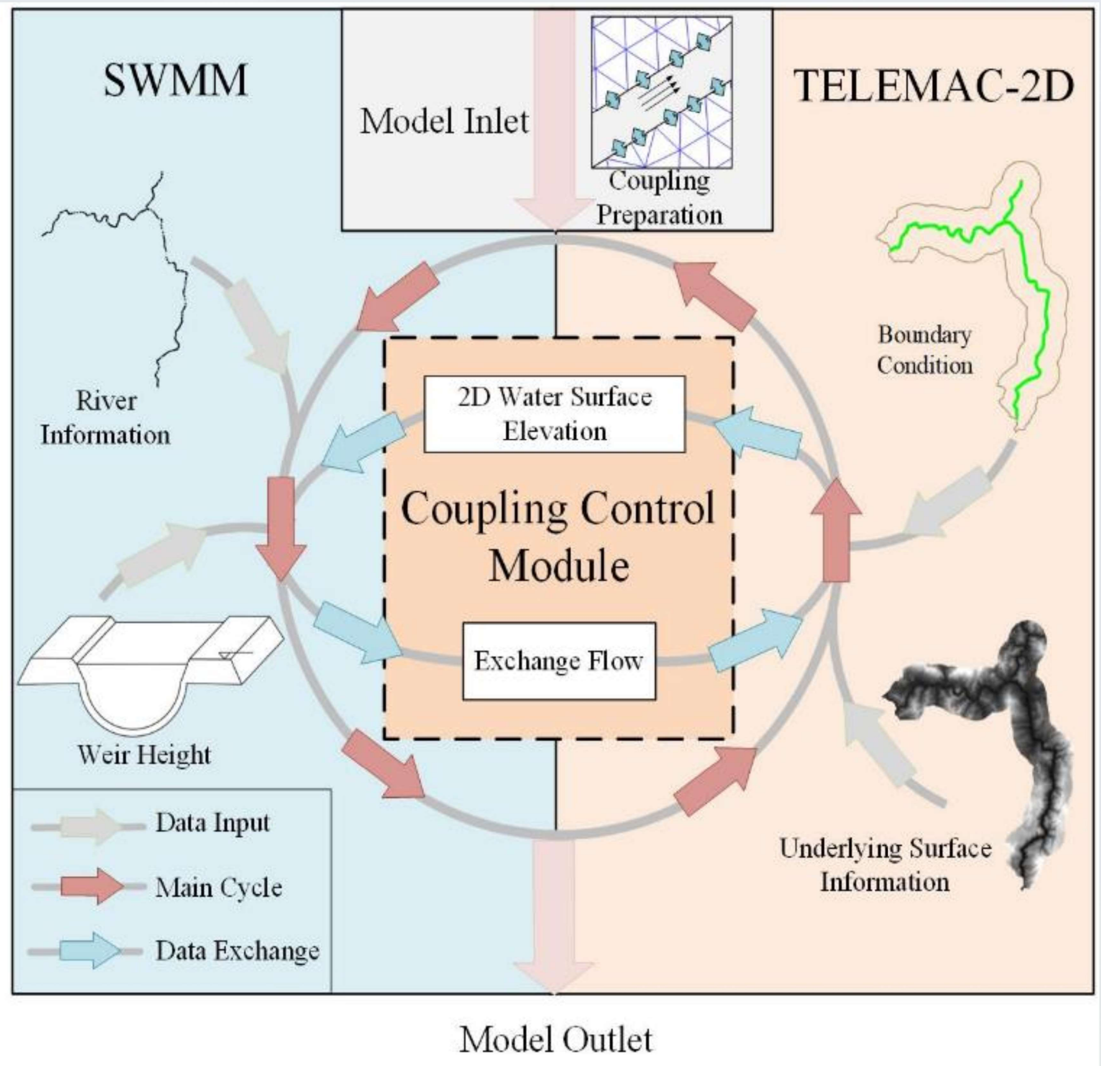
□ Weir equation

$$Q=\begin{cases}0.35bh_{max}\sqrt{2gh_{max}} & if\ \frac{h_{min}}{h_{max}}\le\frac{2}{3}\\ 0.91bh_{min}\sqrt{2g(h_{max}-h_{min})} & if\ \frac{2}{3}<\frac{h_{min}}{h_{max}}\le 1\end{cases}$$

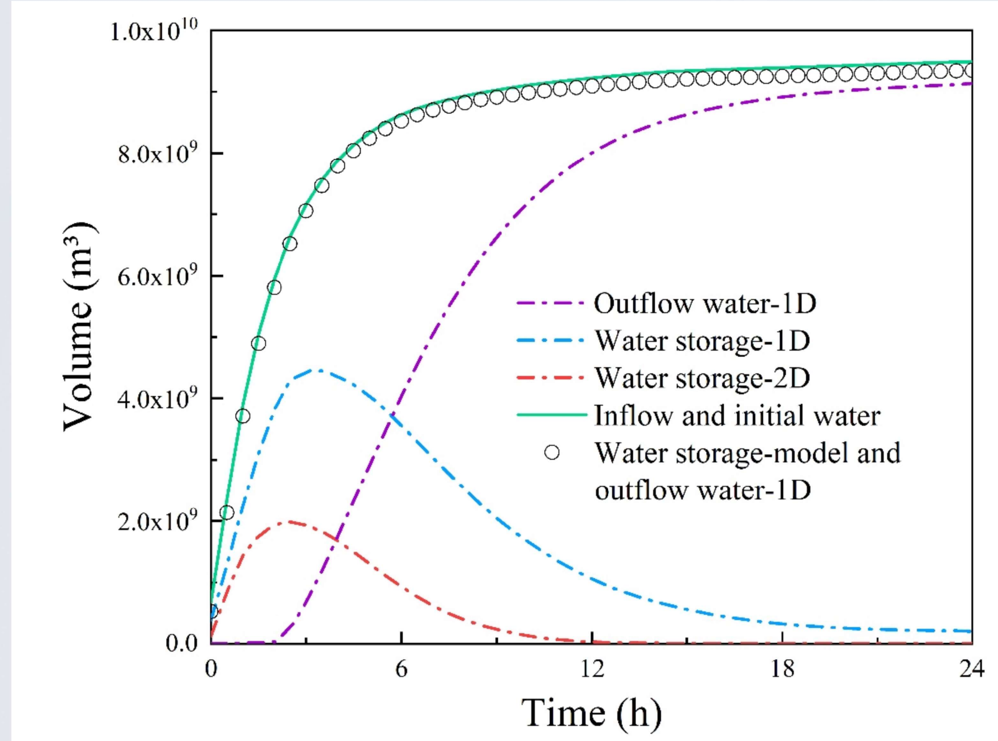
$$h_{max}=max(H_r,H_s)-Z$$

$$h_{min}=min(H_r,H_s)-Z$$

2.2 Coupled hydrodynamic model



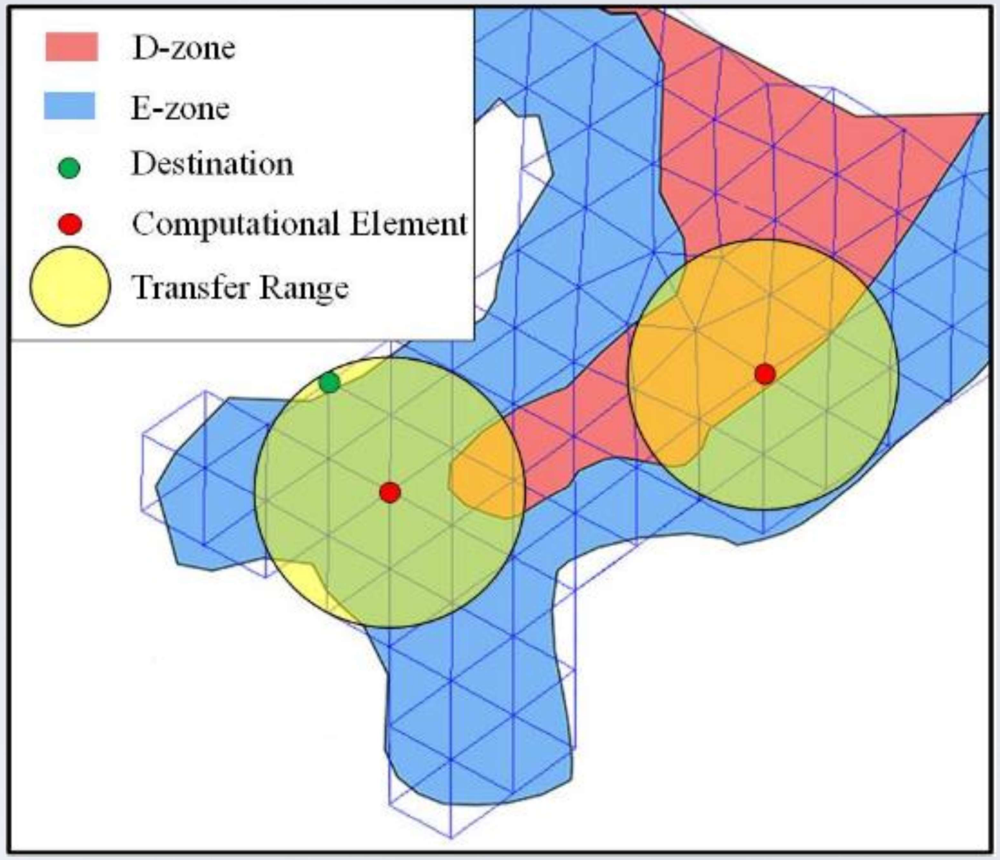
Coupling model operation progress



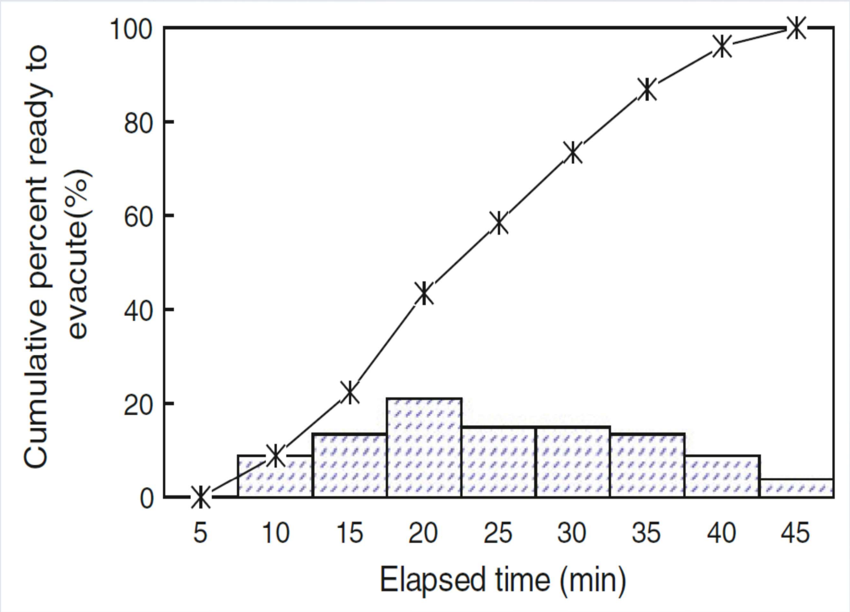
Water balance

- **Step1 Coupling preparetion:**
- **Step2 Operation of the 1D module**
- **Step3 Operation of the 2D module**
- **Step4 Process control**

2.3 Risk zoning method



Risk zoning method



Evaluate probability density distribution of generation time

$$t_T = t_d + t_w + t_p + t_e$$

$$t_{EGT} = t_w + t_p$$

$$t_d = 0$$

Composition of evaluation generation time (EGT)

D-zone → People cannot leave before the floodwaters come

E-zone → People have sufficient time to evacuate

- **Step1 Identify computational elements**
- **Step2 Determine the transfer speed and evaluation generation time (EGT)**
- **Step3 Calculate the transfer range**
- **Step4 Identify D-zone and E-zone**

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3.1 Model construction

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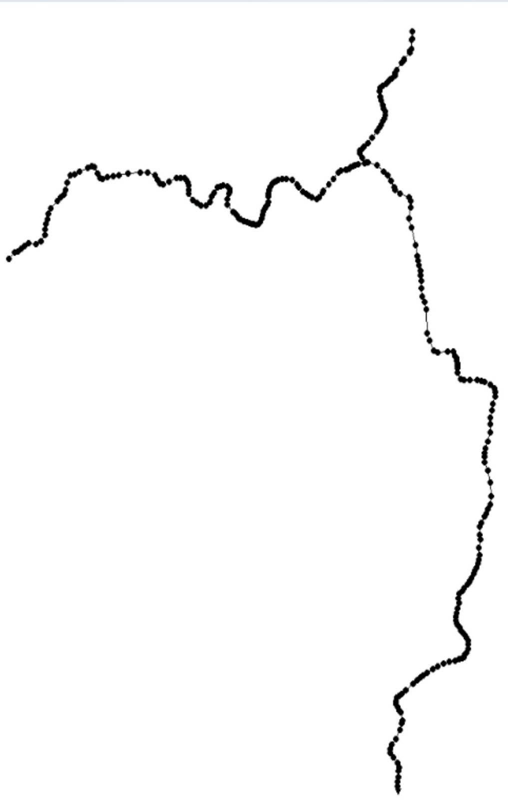
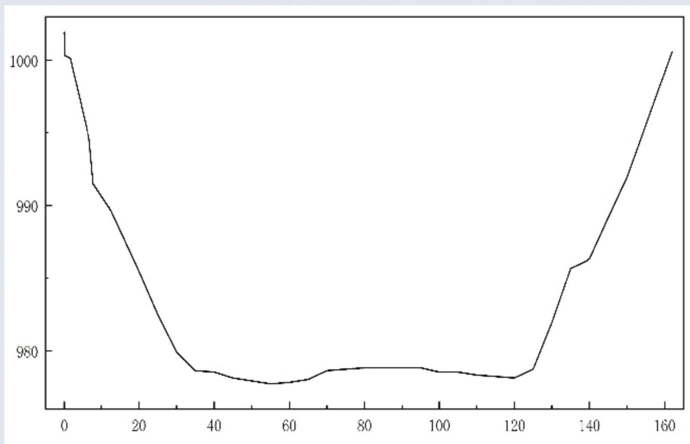
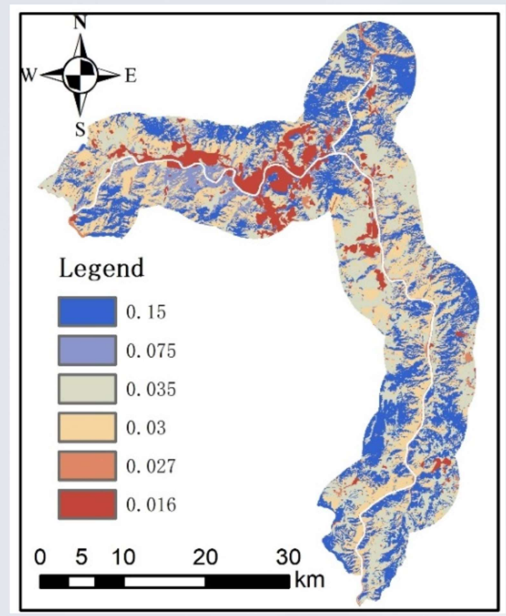
	cultivated land	forestry	grassland	shrubbery	water surface	cities
Manning coefficient	0.035	0.15	0.03	0.075	0.027	0.04



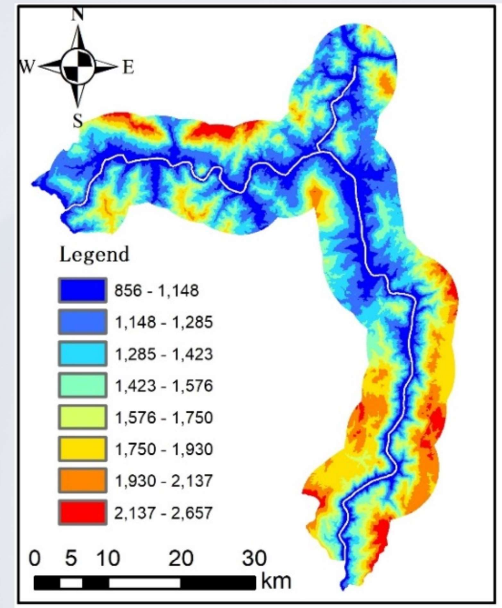
River location



River section



Manning coefficient



Digital Elevation Model (Dem)

The **137 km** long river in the 1D module was split into multiple short sections. Moreover, a surface of **1506 km²** in the 2D module was covered with an unstructured triangular mesh with a **resolution of 30 m**.

3.2 Model calibration and validation

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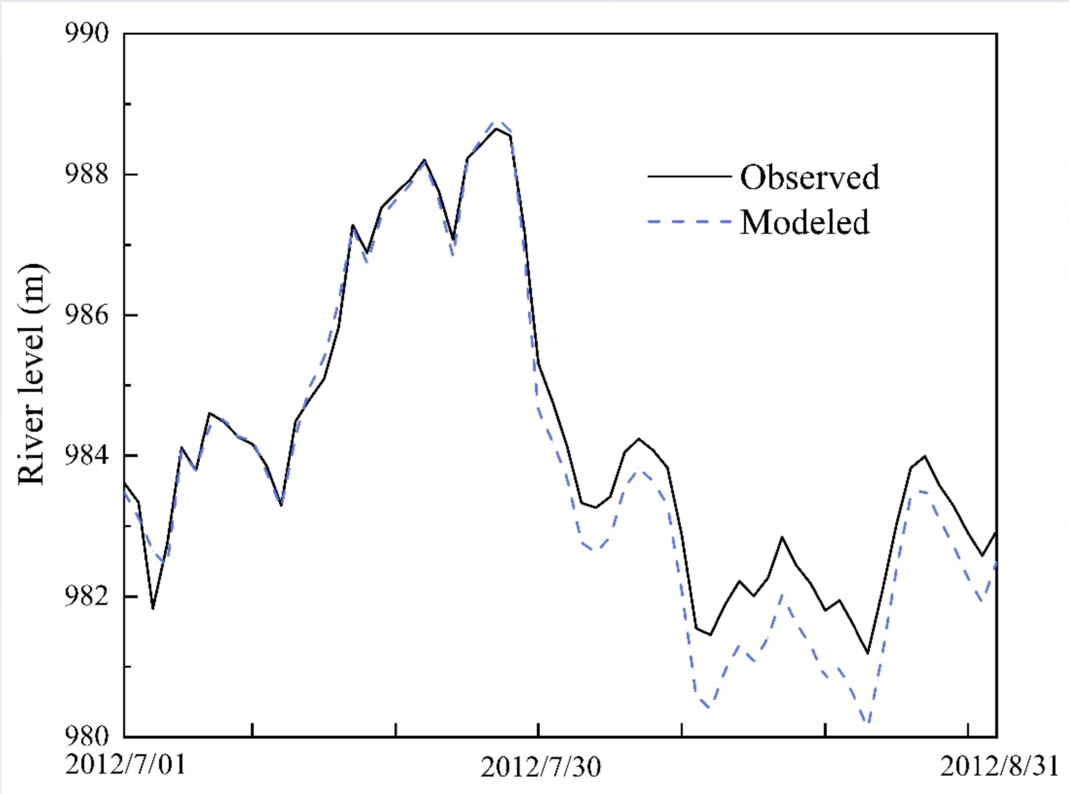


Model validation by river level

$$r = \frac{\sum_{i=1}^{n}(h_m^i - \bar{h}_m)(h_o^i - \bar{h}_o)}{\sqrt{\sum_{i=1}^{n}(h_m^i - \bar{h}_m)^2}\sqrt{\sum_{i=1}^{n}(h_o^i - \bar{h}_o)^2}}$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(h_m^i - h_o^i)^2}{\sum_{i=1}^{n}(h_o^i - \bar{h}_o)^2}$$

This study describes the Manning coefficient of the river channel range obtained from the **barrier lake break flood** of Tanggudong on the Yalong River. In the range of **0.045–0.065**, the Manning coefficient was validated by the observed river level. As expected, the model performed well with **Pearson correlation coefficient (r) of 0.99** and **Nash–Sutcliffe Efficiency (NSE) of 0.93**.

3.3 Manning coefficient

Flood destroyed buildings

Flood destroyed buildings

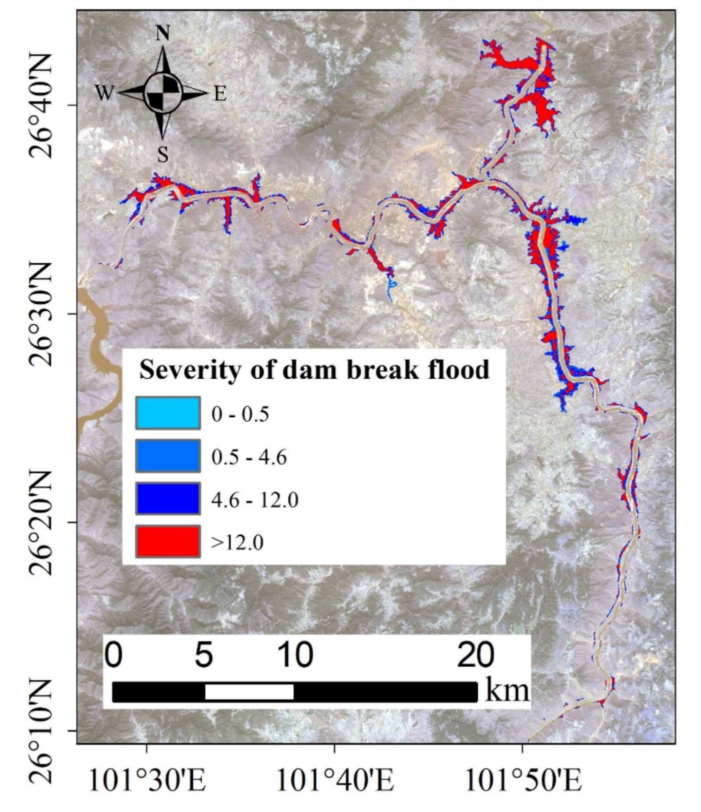
Building risk

$DV = V \times H$

V is velocity, m/s; H represents water depth, m。

$DV < 4.6\ m^2/s$	Low severity
$4.6\ m^2/s \le DV < 12\ m^2/s$	Middle severity
$DV \ge 12\ m^2/s$	**High severity**

In this case, **a reduced Manning coefficient** was used to characterize the water spread following a building collapse in building areas.

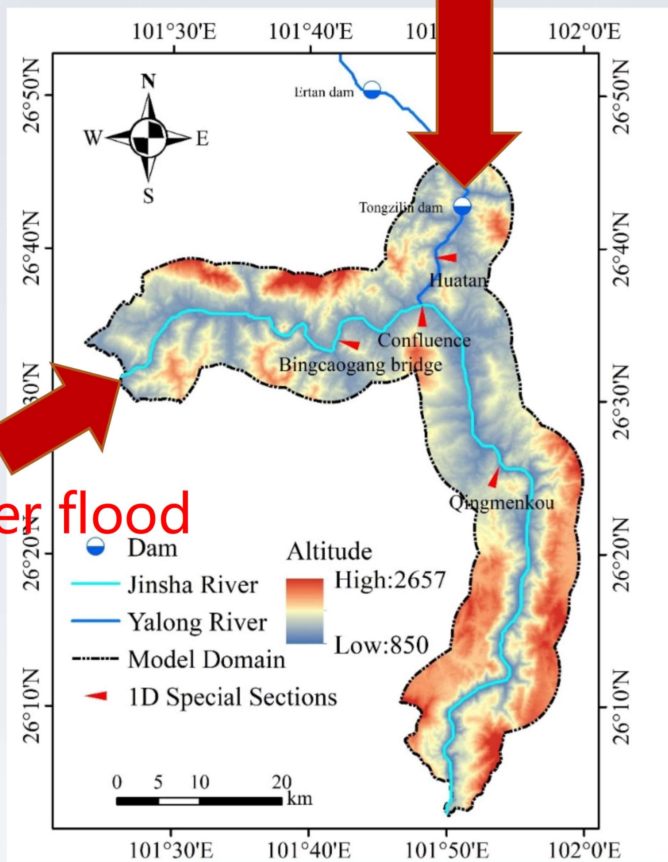


Distribute of building risk

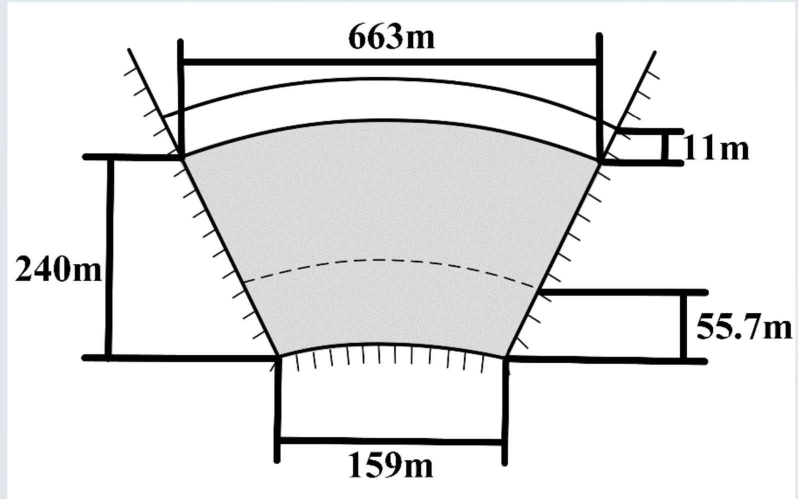
3.4 Flood scenarios

Dam break flood

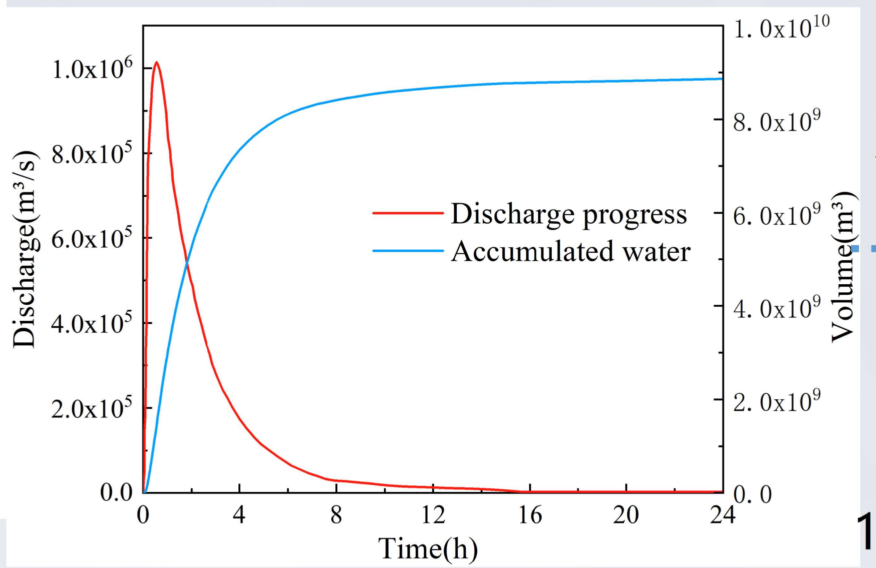
River flood



Flood encounter



Ertan dam section



Dam-break flood hydrograph

Dam break flood

Annual average flow

Scenario 1

(S1)

1000-year return period flood

Scenario 2

(S2)

3.4 Rise zoning scenarios

Scenario1

Scenario2

EGT=30min

Scenario 1-30 (S1-30)

Scenario 2-30 (S2-60)

EGT=60min

Scenario 1-60 (S1-30)

Scenario 2-60 (S2-60)

Two flood scenarios and two different Evaluation Generation Time (EGT) are combined to form **four risk zoning scenarios**. The two EGT is ,**30 min and 60 min** respectively. The detailes of the scenarios is shown in the table.

Flood scenarios	Evacuation generation times	
	30 min	60 min
Scenario 1 (S1)	Scenario 1-30 (S1-30)	Scenario 1-60 (S1-60)
Scenario 2 (S2)	Scenario 2-30 (S2-30)	Scenario 2-60 (S2-60)

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4.1 Flood routing

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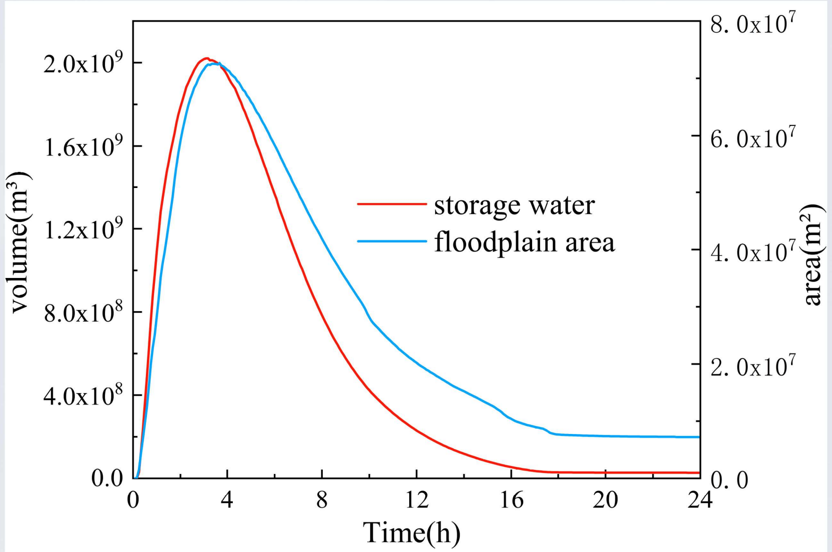
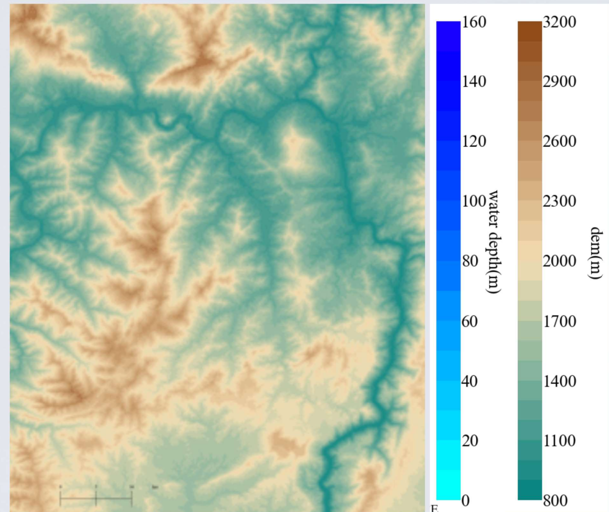
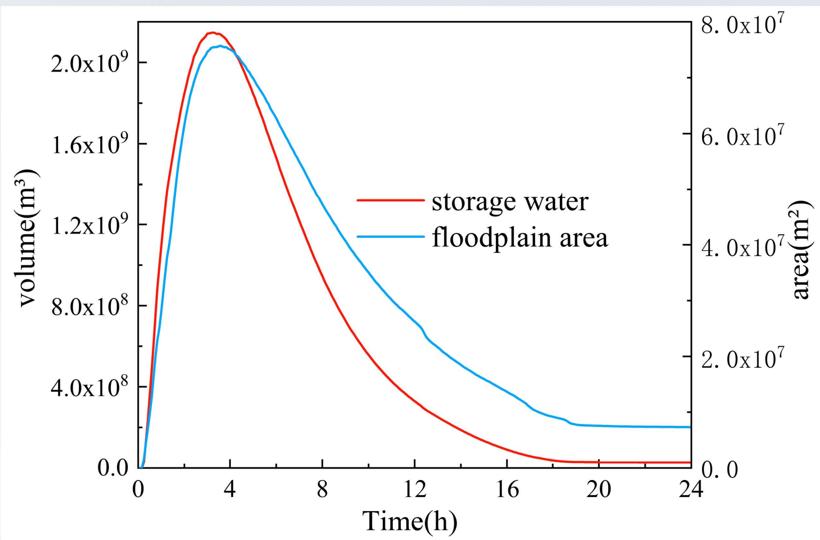


Floodplain and storage water (S1)



Flood spread



Floodplain and storage water (S2)

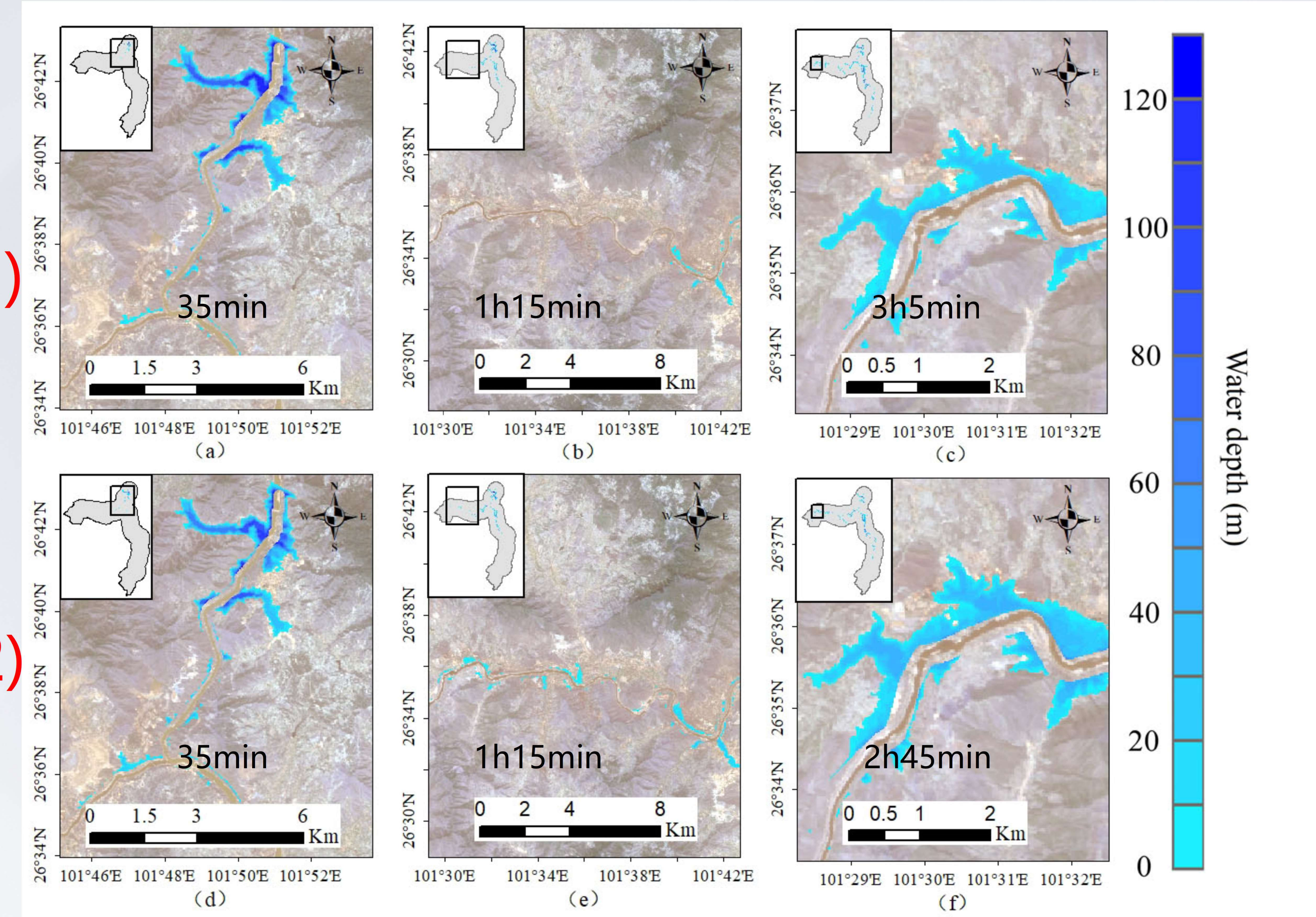
At the junction, the flood will **spread upstream** and down stream along the Jinsha River.

The hydrograph of **the floodplain** is similar to **the water storage capacity** in the 2D model. But the water storage capacity is **close to zero** after 18 hours, while the floodplain is **nearly 7 km²**. This is because some have stored water that cannot flow back into the river. And the water depth in these areas is so shallow that the water storage approaches zero.

4.1 Flood routing

(S1)

(S2)



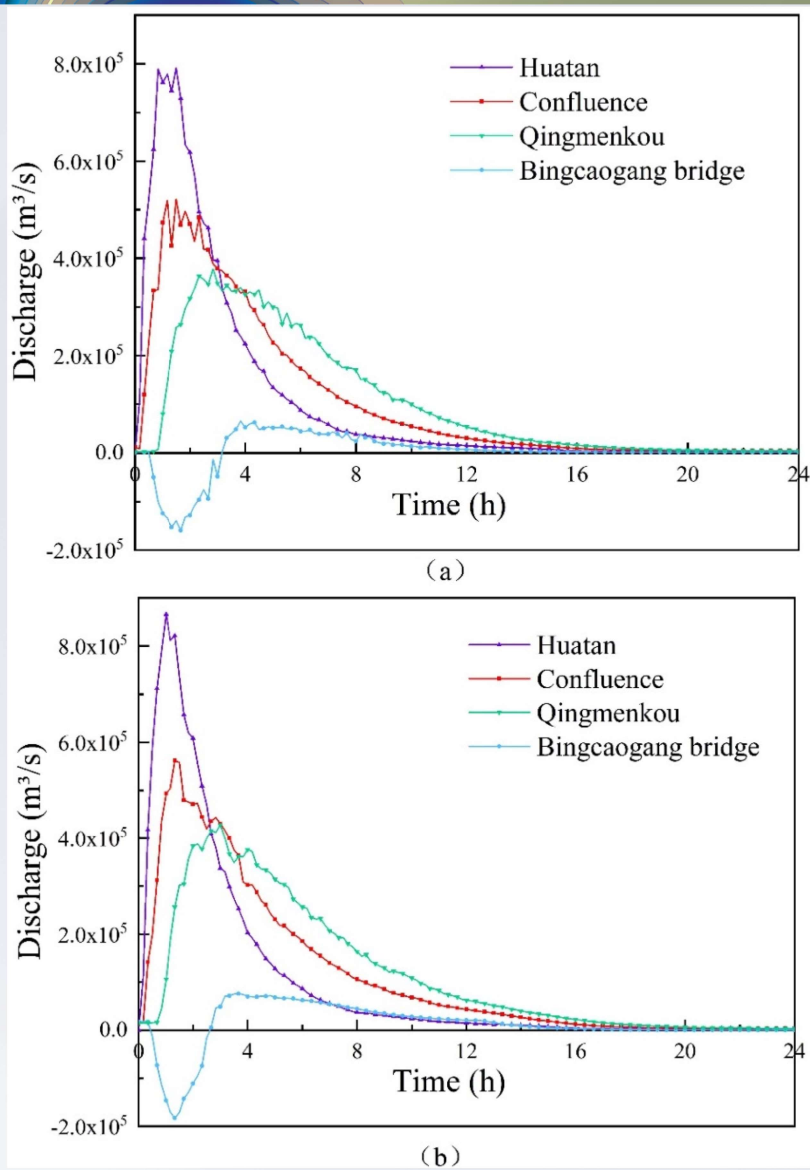
Floodplain spatial distribution

All flood scenarios had a **nearly identical floodplain** in the first 35 min. While the floodplain began to be different as it reached the Jinsha River. In scenario1 (S1) had a floodplain of **43.42 km²** in 1 h 20 min. In contrast, scenario2 (S2), the flood inundated **47.34 km²** in 1 h 20 min. The Jinsha River dam-break flood had varying velocities, which caused difference in the damage.

4.2 River section discharge

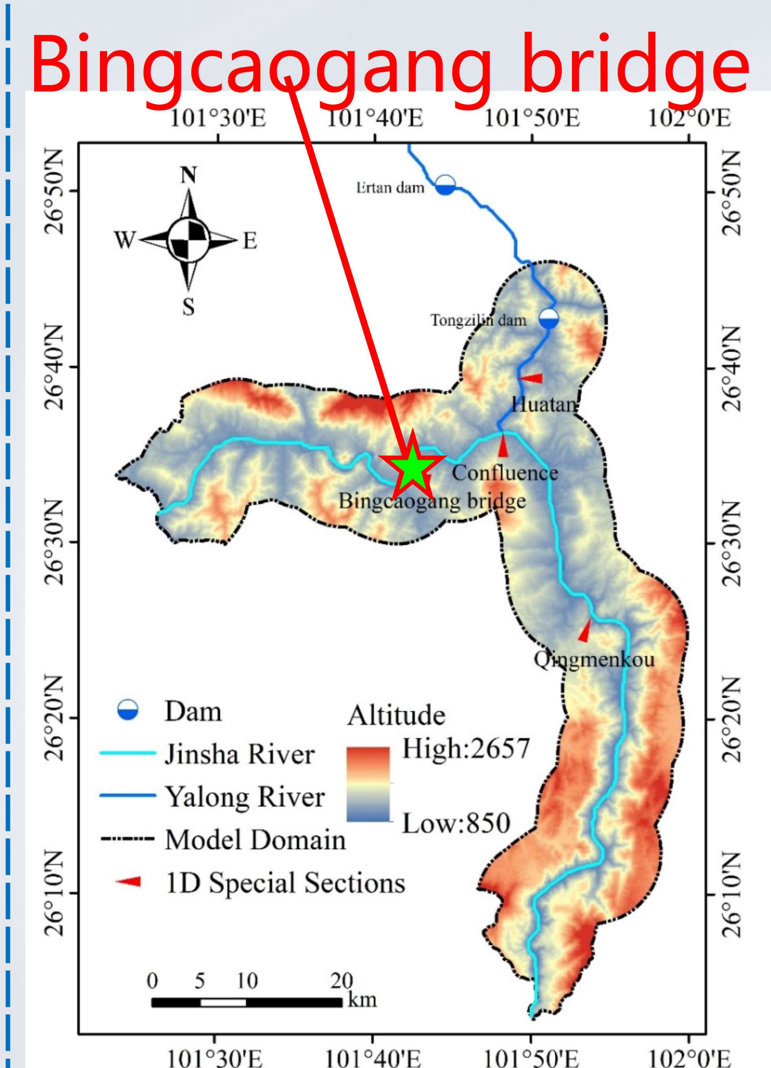
(S1)

(S2)



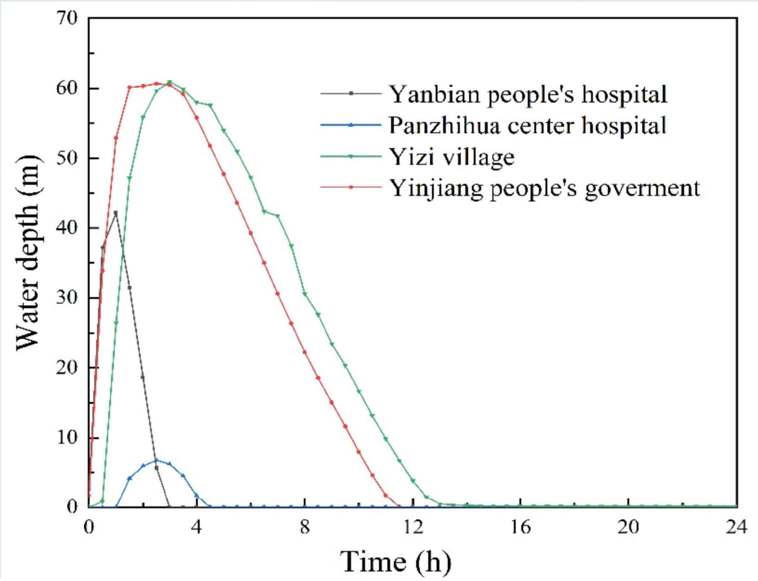
Discharge of river section

The water level variation at the **Bingcaogang Bridge** was unusual. The discharge at the Bingcaogang Bridge abruptly became **negative** shortly after the dam broke, indicating the **arrival of the dam-break flood**. The difference of the **peak flow was 14.42%,** when the difference in **countercurrent duration** across the scenarios was **13.33%**.

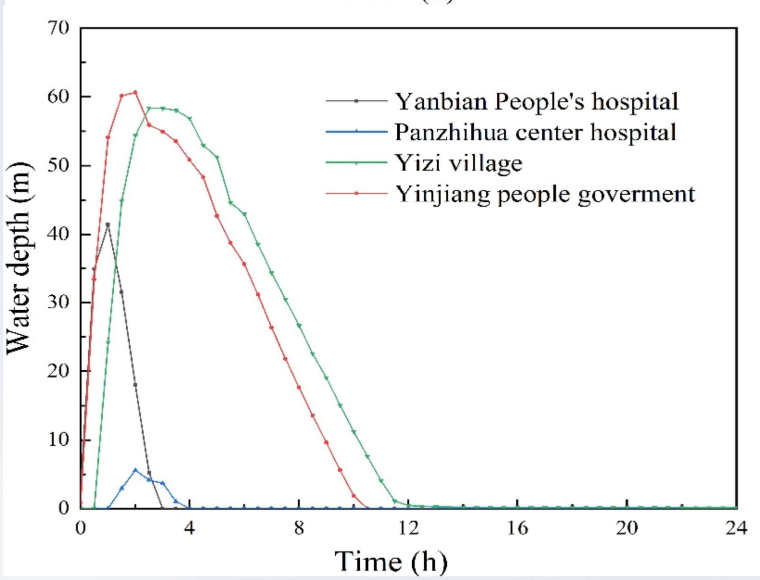


4.3 Special node water depth

(S1)

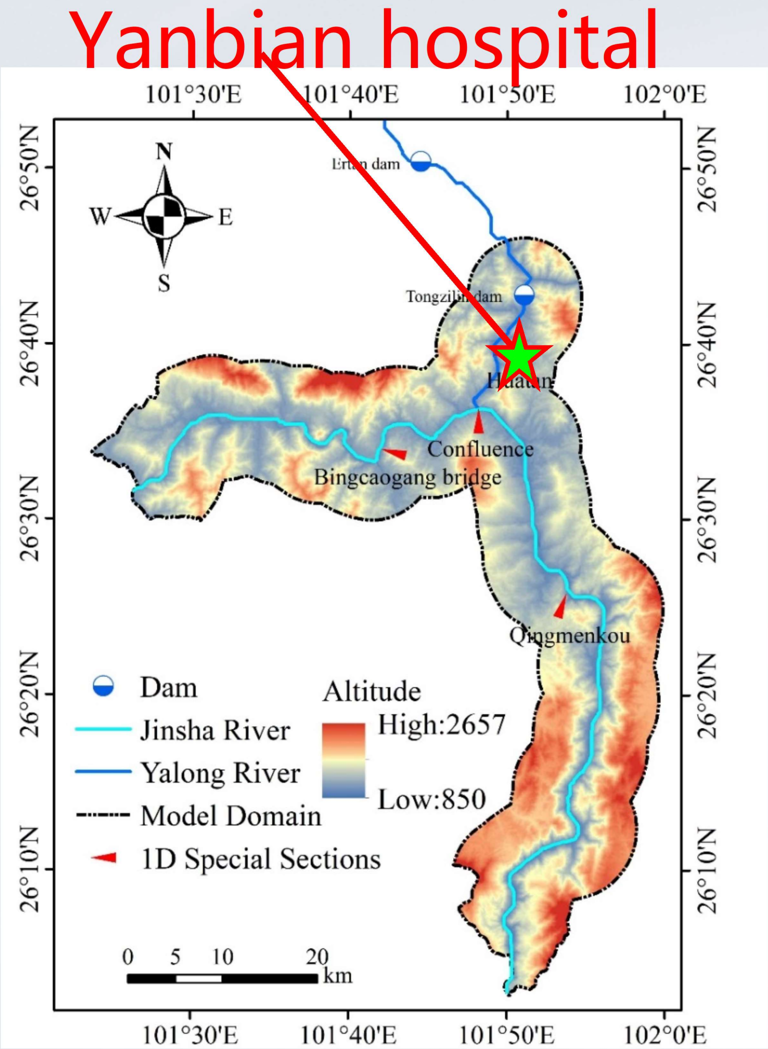


(S2)

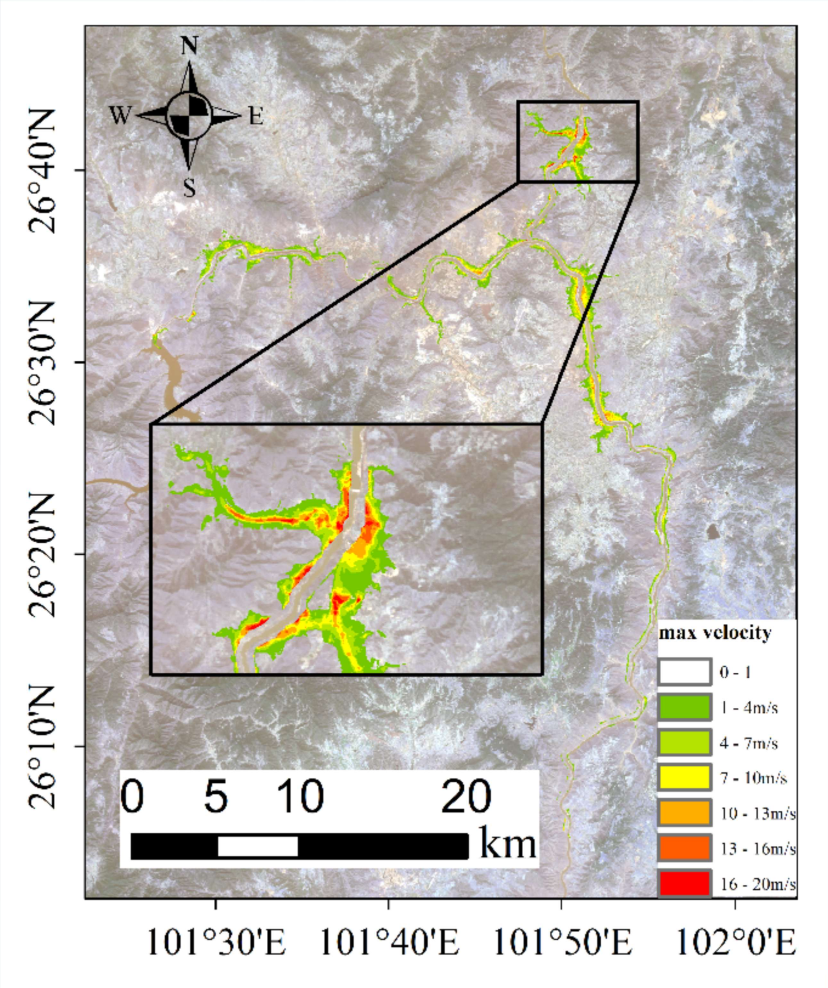


Water depth

As the distance from Tongzilin increases, the **peak water depth** in each section **decreases**. However, the **depth of special points** is different for the different elevations. Yanbian Hospital closes to Tongzilin Reservoir and located on the bank of Yalong River, so the **rising and falling of water depth** in there is relatively **earlier.**



4.4 Flood velocity

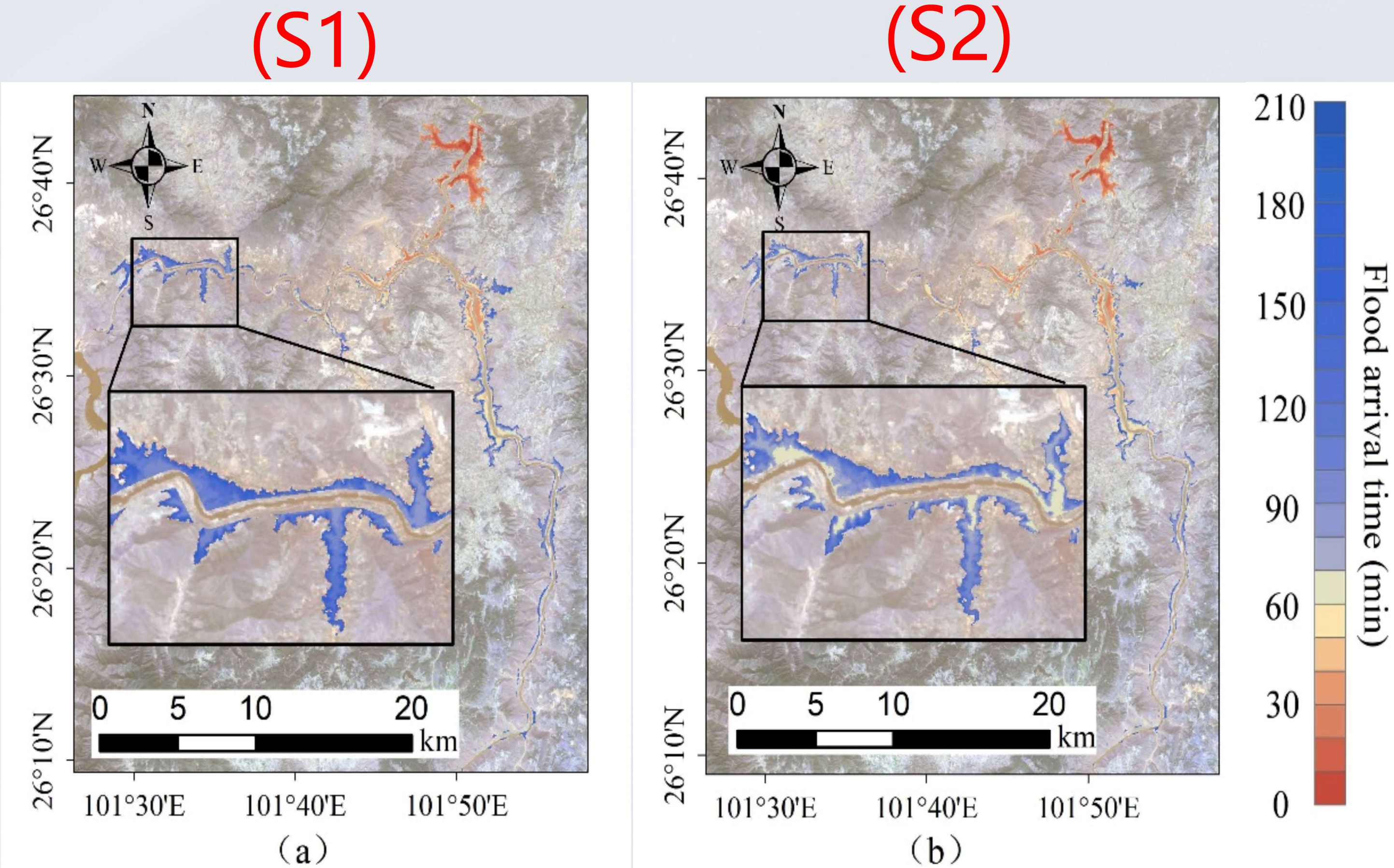


Distribution of velocity

01	Daily velocity in Yalong River	0.5-5m/s
02	Small-sized dam break flood velocity	5m/s
03	Large-sized dam break flood velocity	9m/s
04	Maximum velocity in literature	8-16m/s
05	The average velocity in Yalong River	12m/s

The flood velocity along the Yalong River is higher than other regions. And the **average velocity in there is 12m/s**. That is higher than other researches for the **huge flood**.

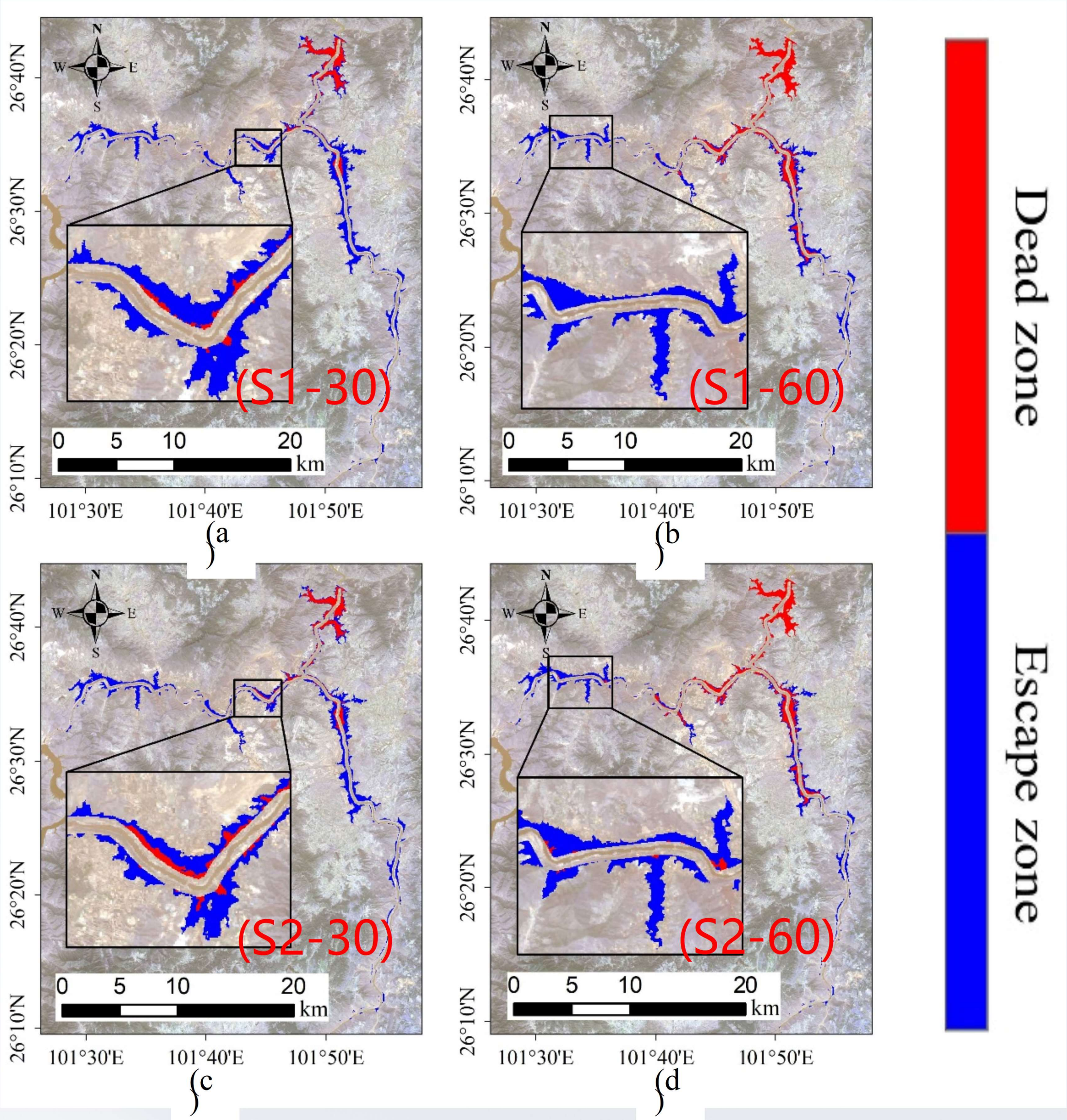
4.5 Risk zoning results



Flood arrival time

Risk zoning is strongly related to the flood arrival time. There were no apparent differences between the Yalong River and downstream of the Jinsha River. However, in the **upstream of the Jinsha River**, the flood arrival earlier in S2 than in S1. The **different flood-wave velocities** in the upstream of the Jinsha River were responsible for this difference.

4.6 Risk zoning results



Distribution of D-E zone

As expected, the disparities between the scenarios are most prominently **observed in the upper Jinsha River.** In particular, the Bingcaogang Bridge **was not included** in the D-zone when the EGT was set to **30 min**. However, Bingcaogang Bridge **was included** in the D-zone when the EGT was increased to **60 min**.

4.5 Risk zoning results

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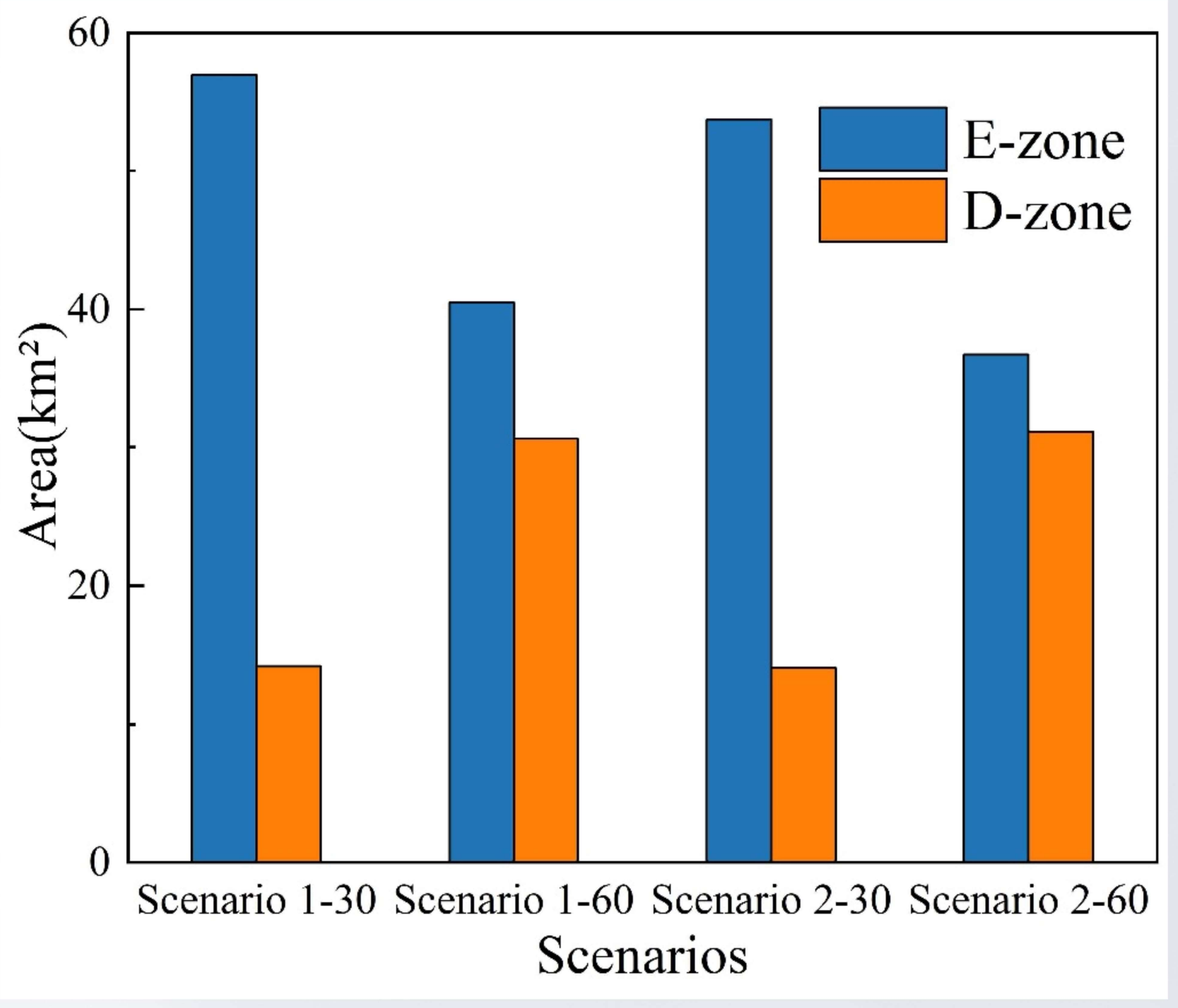
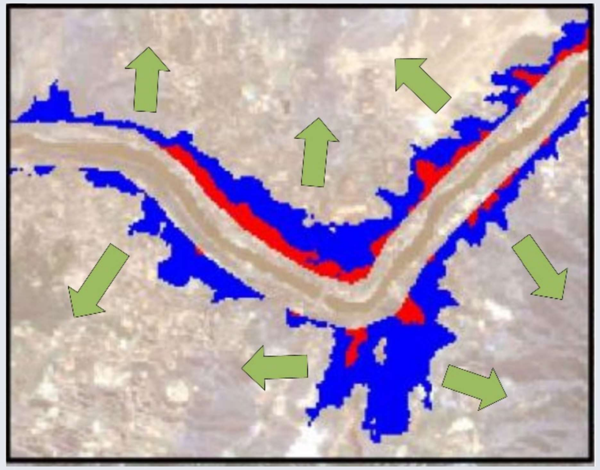


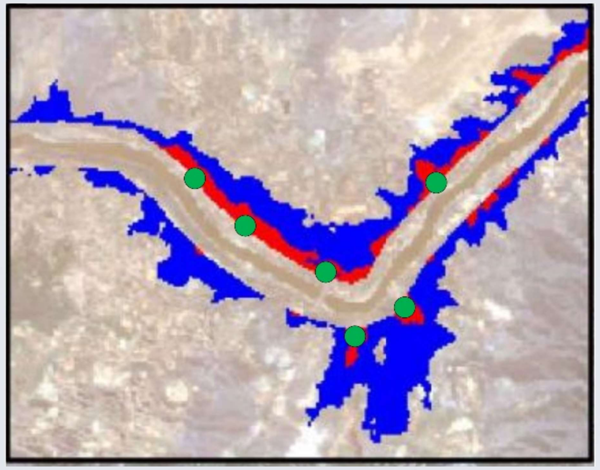
The area of D-E zone

The area of D-zone increases as the EGT increases. When the EGT increased in S1, the **D-zone expanded by 16.47 km² or 116.12%.** Similar trends may be observed in S2, where there is a **17.04 km² increase (120.81%)** between S2-60 and S2-30. Additionally, the D-zone expands by **0.49 km2** between S1-60 and S2-60. This could due to the early arrival of the flood.

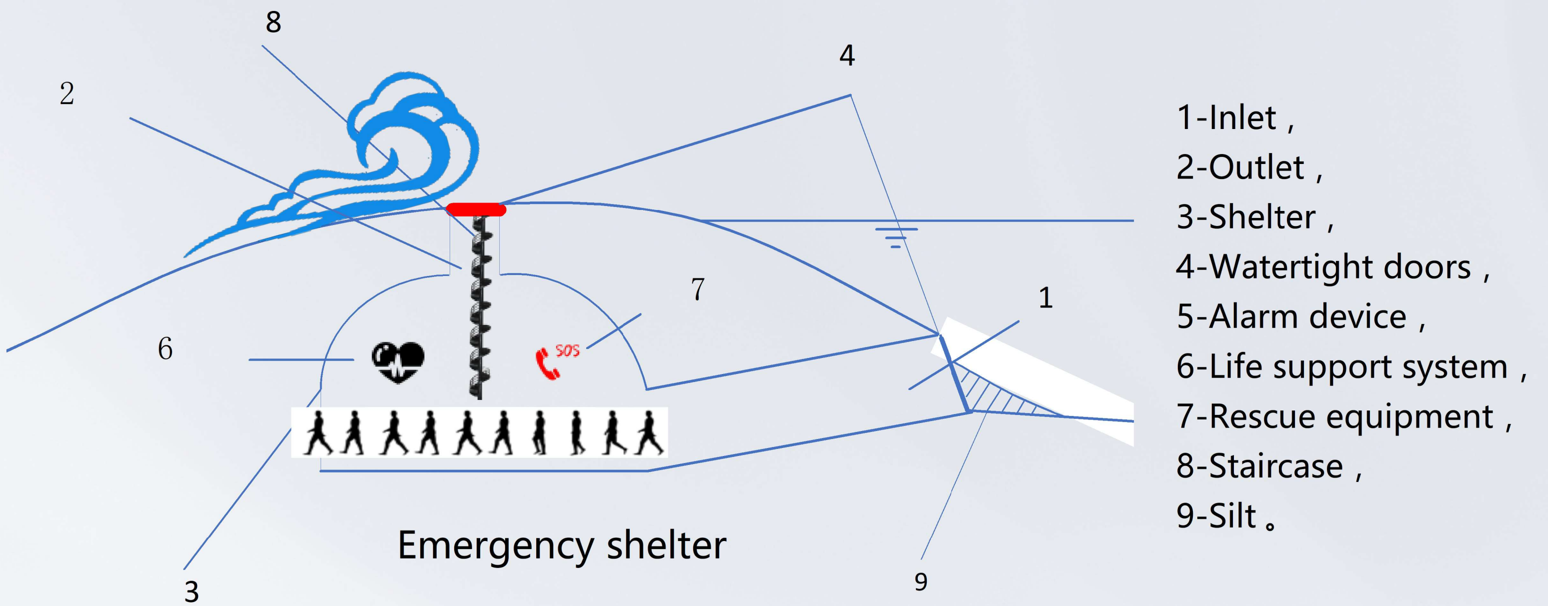
4.7 Possible disaster reduction methods



Direction of evacuation



Location of emergency shelter



Emergency shelter

A floodplain can be divided into several zones based on the risks zoning method, allowing for **targeted flood control and mitigation measures**. In addition, by providing useful data about the distribution of flood risk, this strategy may assist in designing and building projects to mitigate floods. For example, **planning transfer routes** and **building emergency shelters**.

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5 Summarize

- A new **coupling model** was developed to couple river networks and surface flows.
- A **20 min reduction** in the duration of the reverse flow is caused by the flood inflow (1000-year return period) of the Jinsha River.
- When the evaluation generation time (EGT) increased from **30 min to 60 min,** the **D-zone dramatically increased** in both flood encounter scenarios.

- The lack of **recorded datasets** of extremely huge floods led to incomplete model validation.
- The research does not consider the **coupling impact** between floods and buildings.
- More **comprehensive transfer plan** need be considered to obtain more accurate zoning results.

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