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Impact mechanism of soil moisture re-distribution on runoff generation in hillslopes and early warning of flash flood

Yangwen Jia, Cunwen Niu, Chunfeng Hao, Junkai Du, Jiajia Liu

State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research (IWHR)

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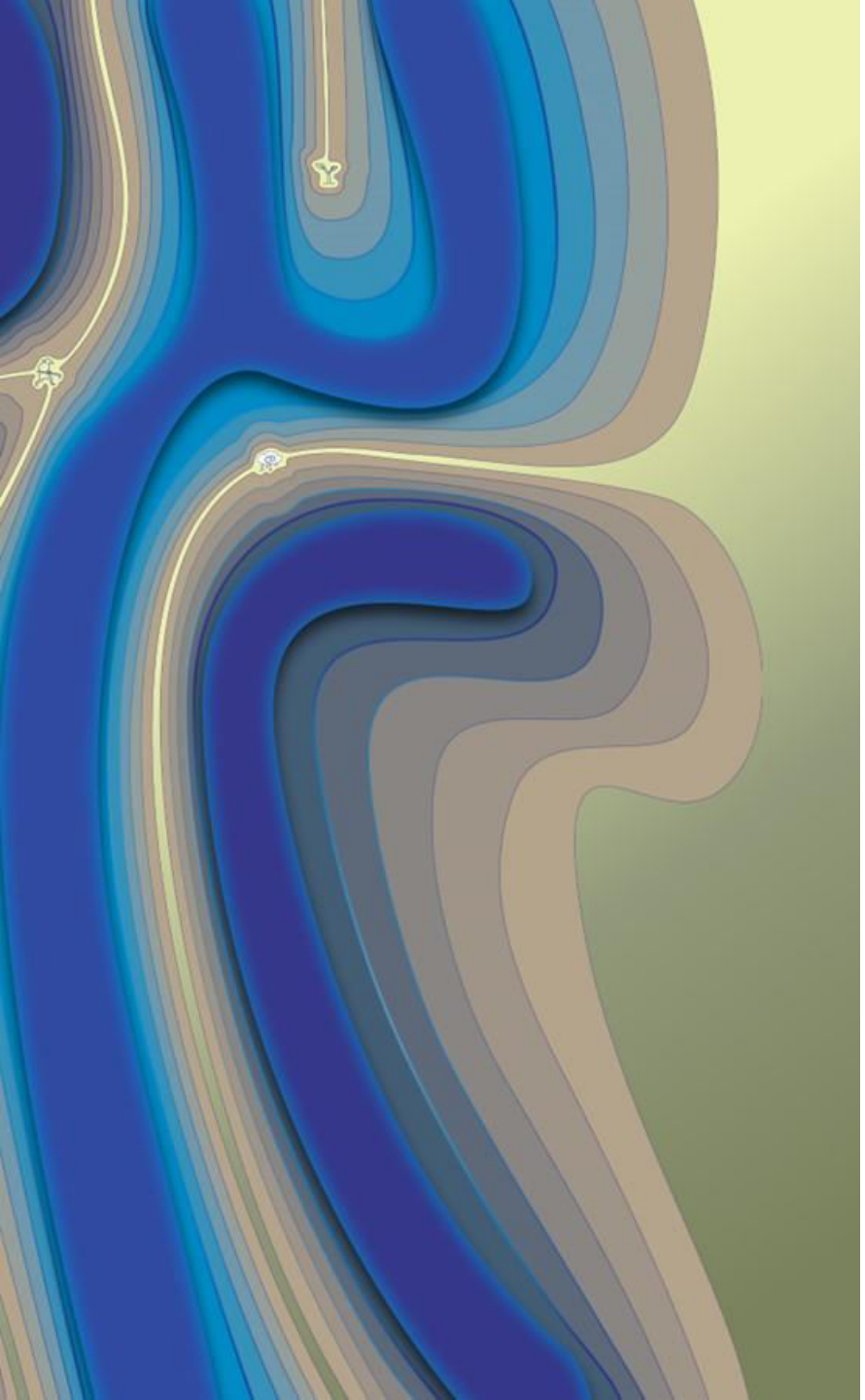

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■ Flash Flood

Definition：Storm-induced rapid rise and fall flood in small rivers in mountainous areas.

Disasters of flash flood： In 2022, 1002 global events， impacted people: 2.6 billion. In China, flood-hit population: 34 million， the dead and lost: 171 persons， direct economic loss: 129 billion RMB Yuan.

Global disaster data platform

Wenchuan “8·20”

Zhouqu “8·7”

Lingyun “6·17”

Haihe “23•8” (Beijing)

Existed problems and challenges

- Difficulties for simulation and forecast due to high intensity and short duration of storms, short concentration time in small rivers in mountain areas
- Lacking of measure data and representativeness of measured data is low
- **Most existed models do not reflect impact mechanism of soil moisture re-distribution on runoff generation in hillslopes (topographic effect)**

Study framework

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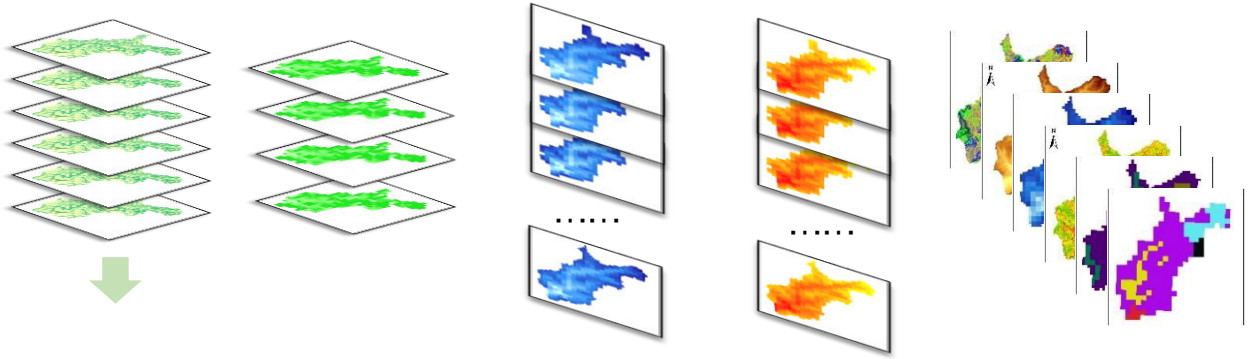
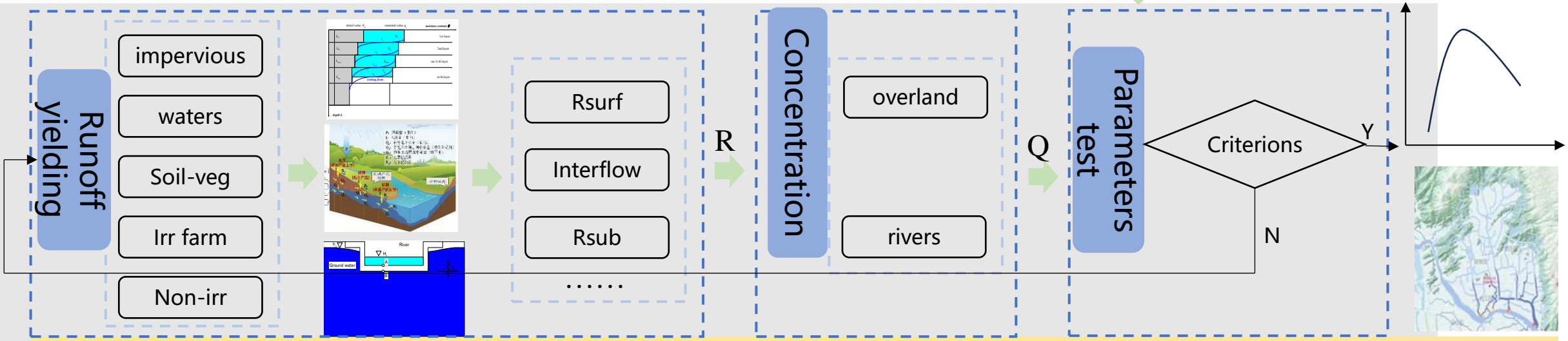
Multi-source data

Data processing and fusion

LULC | Veg | Rain | Ta | DEM & Soil





WEP model-based Flash Flood Modeling (WEP-FFM)

WEP-FFM model

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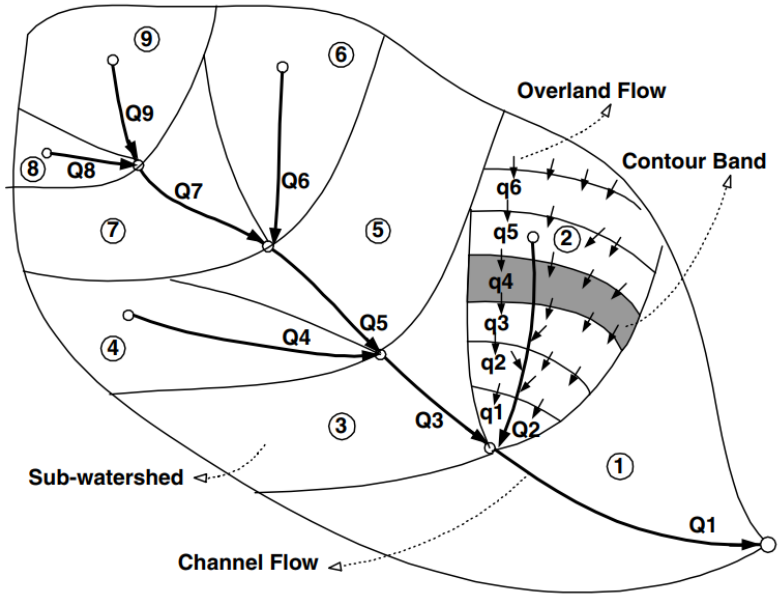
■ **Soil moisture re-distribution (3D):**

1) The multi-layer Green-Ampt model is for infiltration-excess (1D)

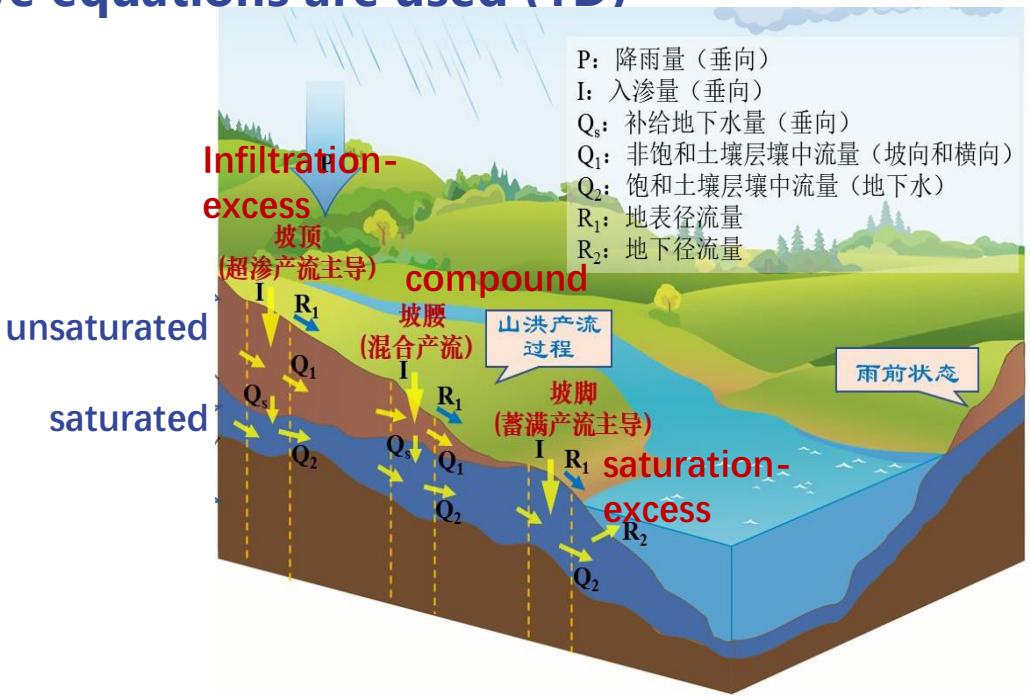
2) The Richard equation is used for vertical soil moisture movement in unsaturated soil layers (1D)

3) The Boussinesq equation is adopted for saturated soil water movement in hillslopes (2D)

4) Overland and channel flows: the kinematic wave equations are used (1D)



Horizonal structure



Vertical structure in a hillslope

Model parameters

4 groups:

1) Water storages

2) Evapotranspiration

3) Subsurface runoff

4) Surface runoff

Main parameters

Groups	Names		Ranges
Water storages	Modification coefficient for aquifer thickness		2~25
	Thickness of 1st soil layer		0.1~0.8
	Thickness of 2nd soil layer		0.2~1
	Thickness of 3rd soil layer		0.3~2
Evaportranspiration	Modification coefficient for canopy resistance		0.1~10
Subsurface runoff	Saturated hydraulic conductivity of soil		0.1~2
	hydraulic conductivity of riverbed material		0.1~1
	horizontal hydraulic conductivity of aquifer		2~10
Surface runoff	Depression storage depth (mm)	forest	20~90
		Grassland	10~60
		bareland	2~20
		Slopy farmland	5~30
		Raddy field	80~160
		Irrigation crops	50~120
		Non-irrigation crops	40~100
		Siil-arrested dams	80~300
		Paddy land	60~200

Applications: 1) Qingxi river, Sicuan province

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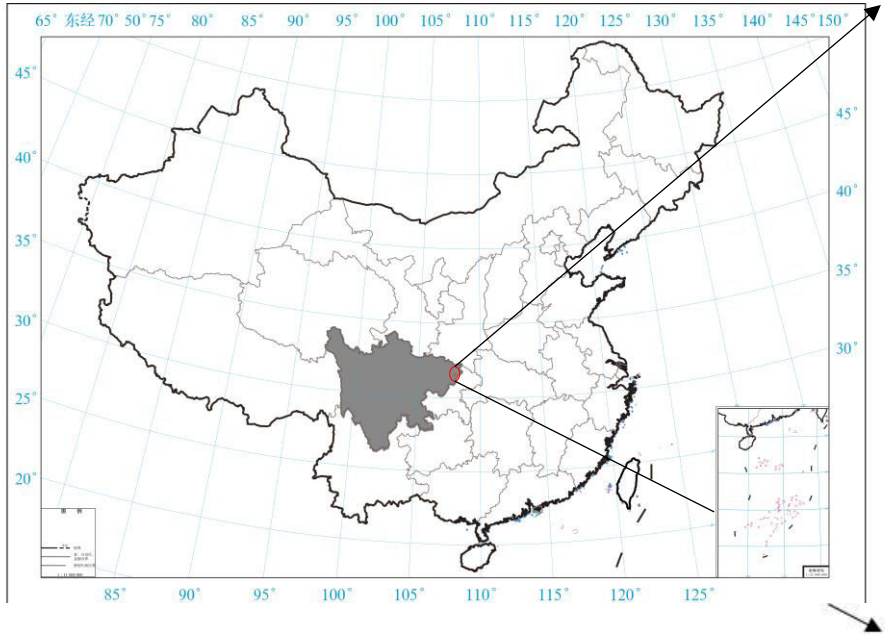
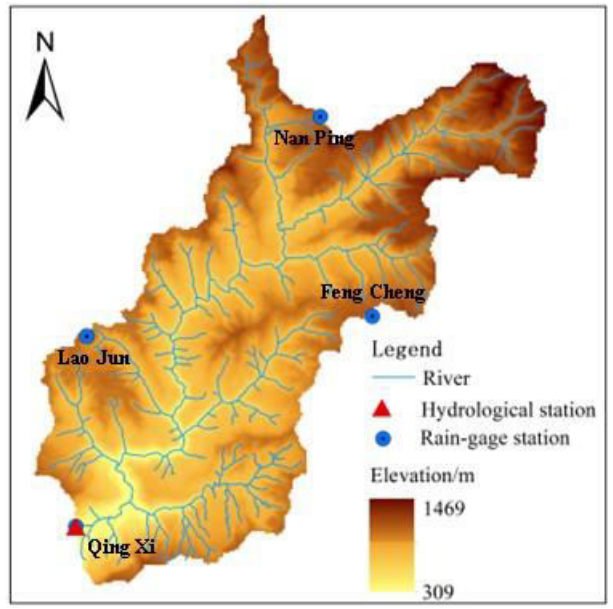
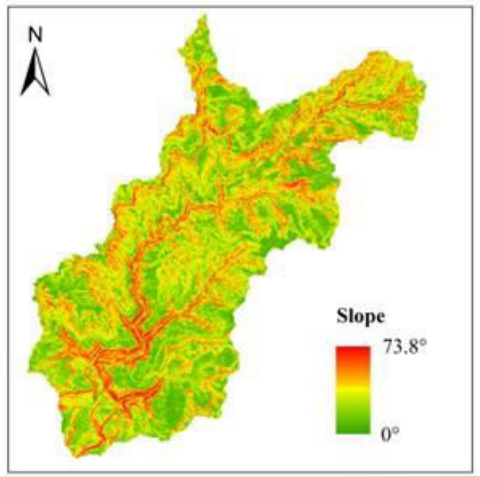
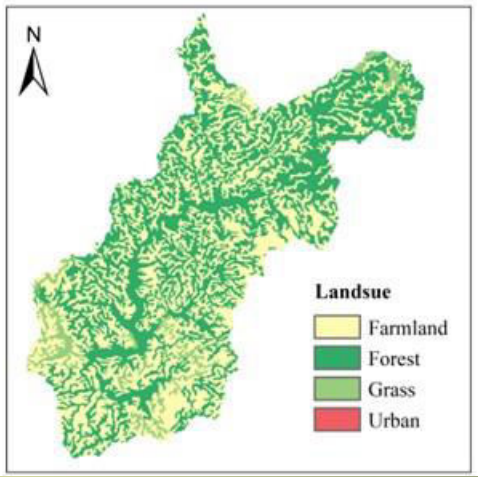
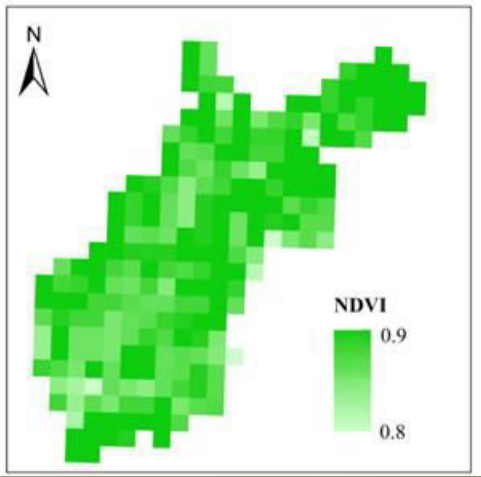
- **Qingxi river watershed**
  - Area: 297 km^2;
  - River characteristics : channel gradient(16‰), river length (44 km);
  - Average precipitation: 1239.4mm;
  - Average temperature: 16.8 ℃;
  - Average altitude: 329~1516 m;
  - Main land use types: Forest, Grass, Farmland;
  - Main soil types: purple soil, paddy soil, yellow soil;











Applications: 1) Qingxi river, Sicuan province

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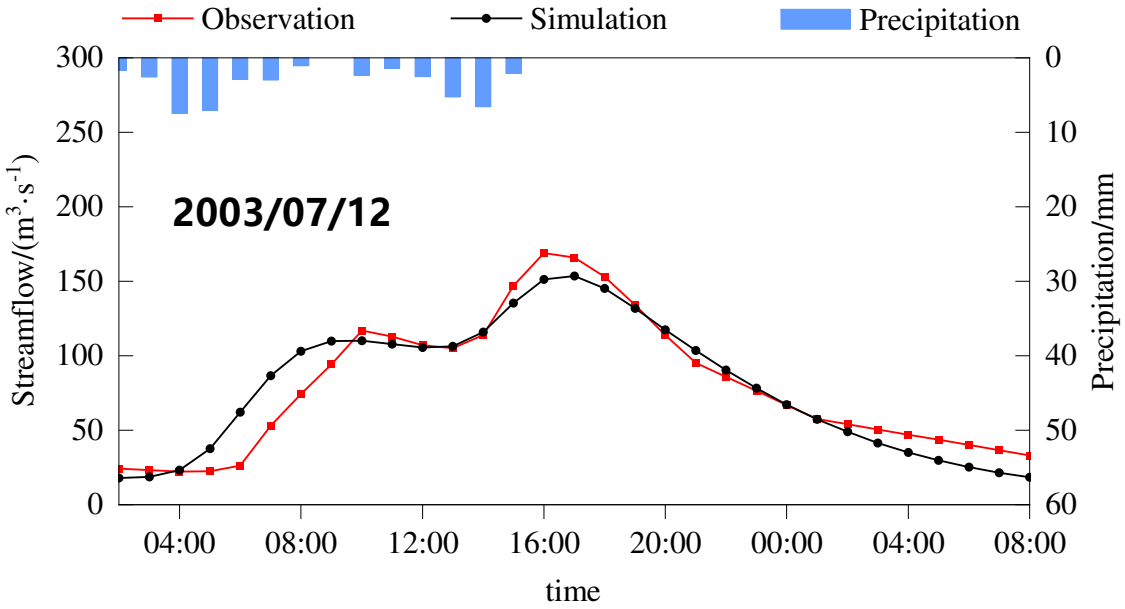
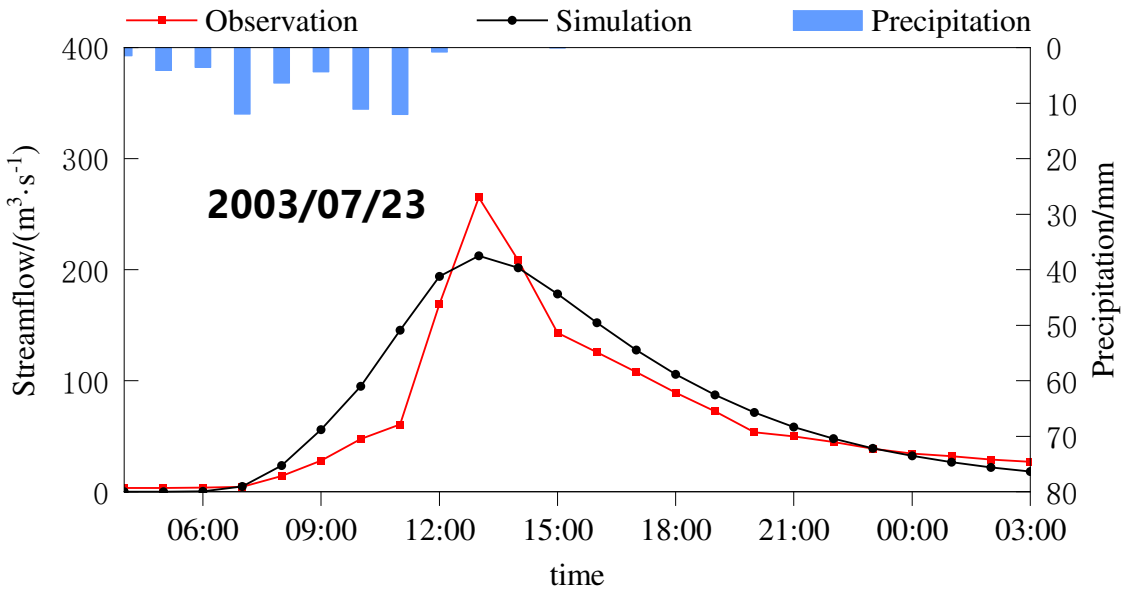
Simulation of flood events

- Flood No. 20030712: The measured flow and simulated flow fit well. The NSE of this flood was greater than 0.90, R^2 was 0.90, peak present time difference was 0 h, the error of flood peak was less than 10 %.
- Flood No. 20030723: The NSE of this flood was 0.77, R^2 was greater than 0.80, peak present time difference was 0 h, the error of flood peak was less than 20%.



NSE	R^2	Peak time error/h	Flood peak flow error(%)
0.91	0.91	0h	-9%



NSE	R^2	Peak time error/h	Flood peak flow error(%)
0.77	0.87	0h	-11%

Applications: 2) upper Fuchun river, Zhejiang prov.

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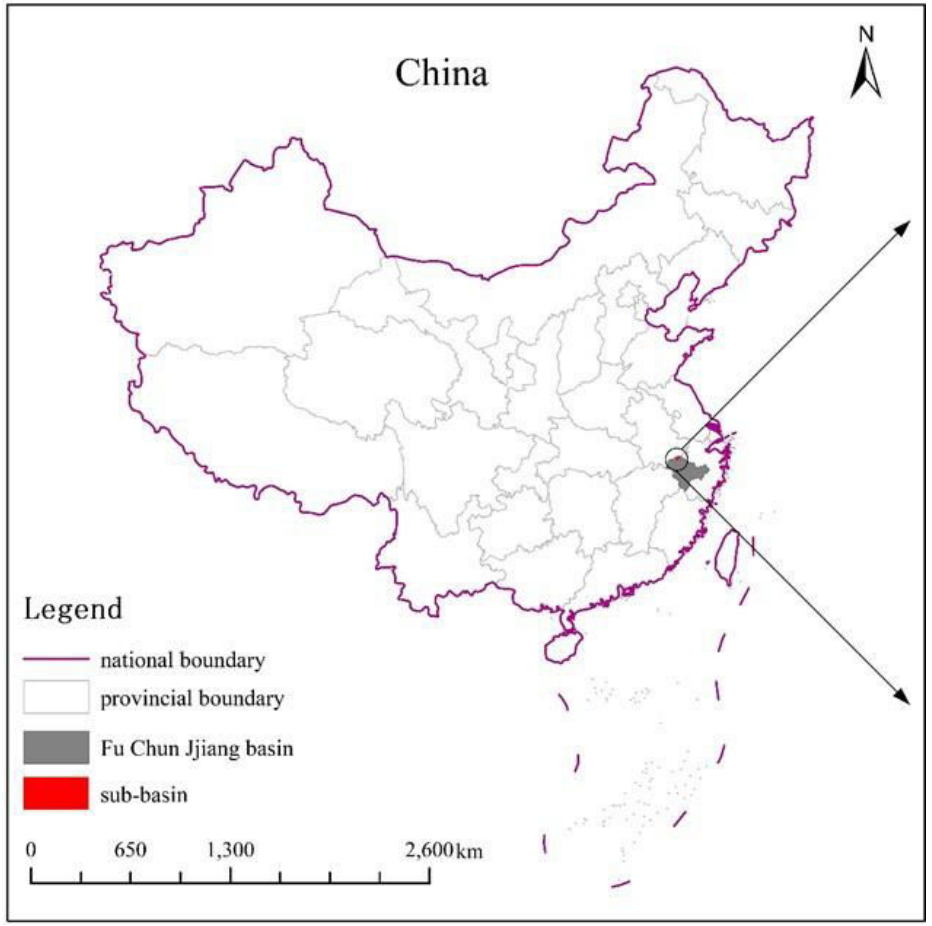
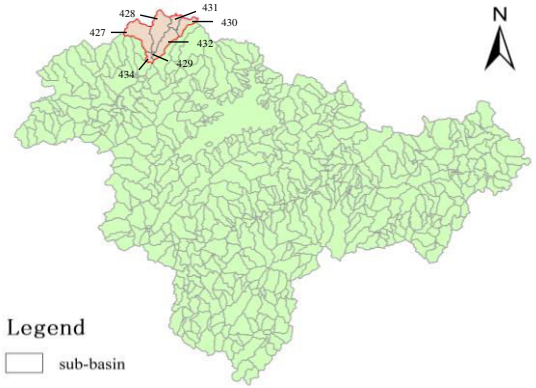
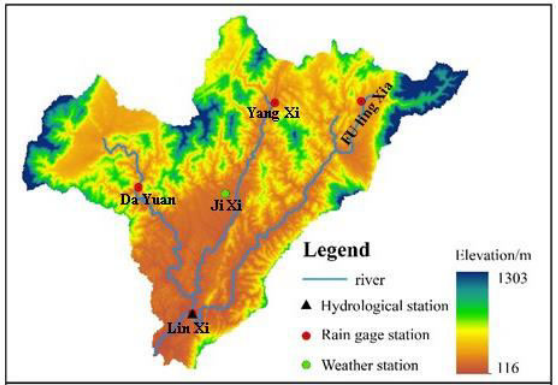
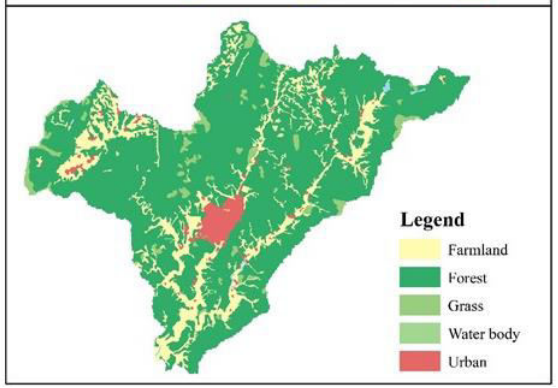
Sub-basin 434 (Linxi) in upper Fuchun river basin

- Area: 562.5 km^2;
- Average precipitation: 1625 ~1789 mm;
- Average temperature: 11.8~ 17.4 ℃;
- Average altitude: 382 m;
- Main land types: Forest (76. 3%), Farmland (16.3%);
- Main soil types: red loam (55.1%), paddy soil (21.8 %), ske-leton soil (10.1%);









Applications: 2) upper Fuchun river, Zhejiang prov.

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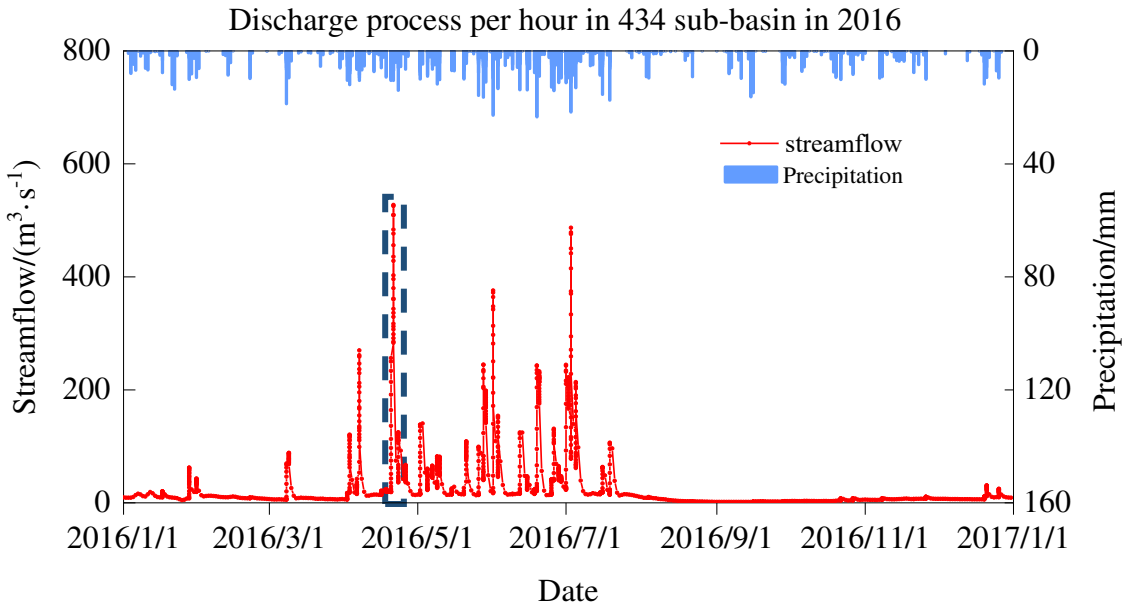
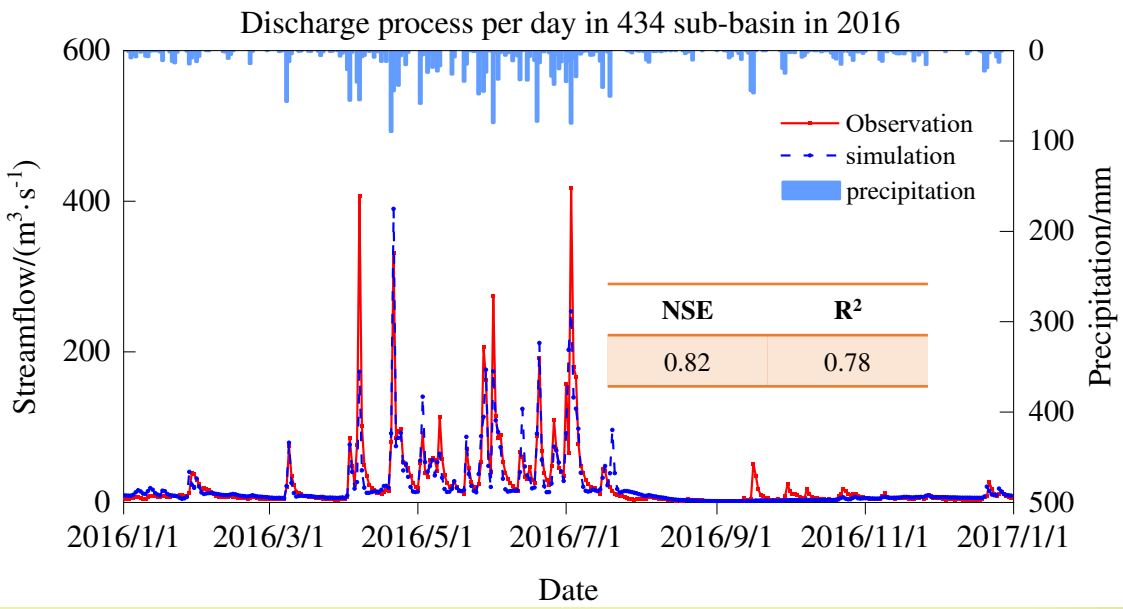
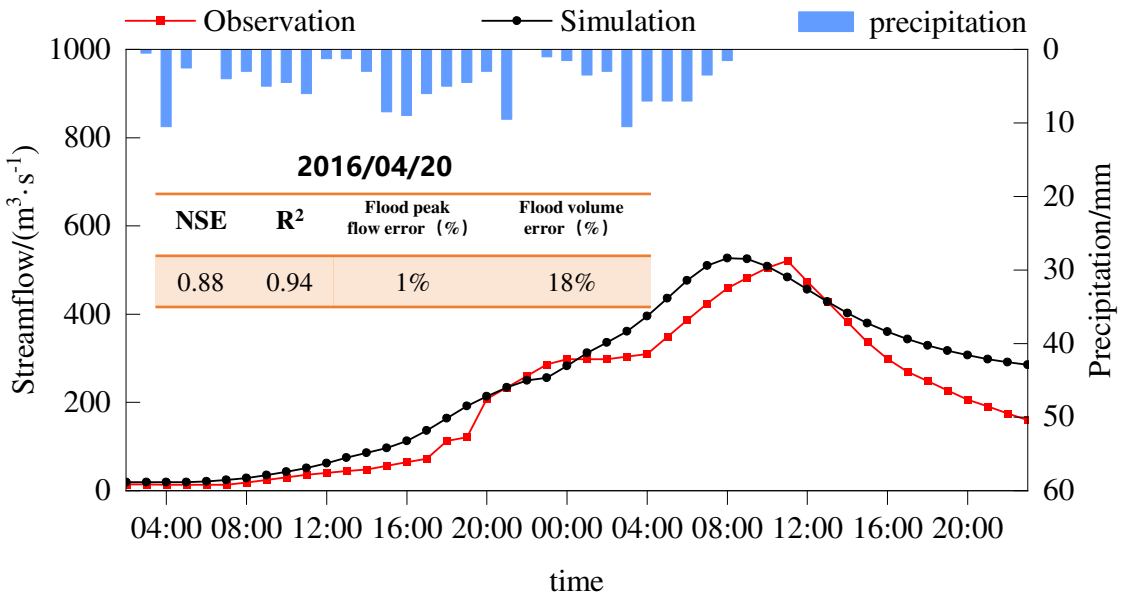
- **Flood simulation of 434 sub-basin (562.5km²)**
  - **Hour**: The NSE of 20160420 flood was greater than 0.8, the R^2 is greater than 0.9, and the error of flood peak and flood volume was less than 20 %.
  - **Day**: The measured and simulated flow process line fit well, NSE was greater than 0.8.







Summary

- Based on the multi-layer Green-Ampt infiltration model and two-dimensional saturated soil water simulation, a distributed flash flood model （WEP-FFM）is suggested to reflect the impacts of soil moisture re-distribution on runoff generation in hillslopes.
- The WEP-FFM model is developed and primarily validated in the case study watersheds.
- A further study will be performed hereafter to evaluate the model effects to flood simulation accuracy improvement, and to put forward **the quantitative factors (like rainfall intensity and amount, soil moisture content correspondent to different hill slopes, soils and river lengths etc.)** and early warning thresholds of flash flood under the combined influence of climate and landform.

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Thank you very much for your attentions!