Paleoflood Events in the Yunxian Section of the Upper Han River during the Northern Song Dynasty (Postprint)

Authors: Wang Guangpeng, Zha Xiaochun, Huang Chunchang, Pang Jiangli, Zhang Guofang, Xiaochun Zha

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Abstract

Paleoflood hydrology research constitutes a frontier science within the field of global change studies. Through compilation of recent paleoflood research findings, it has been discovered that four sedimentary profiles in the Yunxian reach of the upper Han River—Yanjiapeng (YJP), Shangjiahe (SJH), Guixianhe Estuary (GXHK), and Mituo Temple (MTS)—all record paleoflood events from the Northern Song Dynasty period (960–1127 CE). By investigating the river reaches where these four sedimentary profiles are located, and based on measured river channel cross-section data, hydrological parameters, and a designed paleoflood discharge hydrograph, the HEC-RAS model was employed to simulate the routing process and water surface profile of the Northern Song Dynasty paleoflood. Furthermore, the 2010 "7 · 18" flood event was utilized for model reliability validation. The results demonstrate that: compared with surveyed paleoflood water levels, simulated water level errors at the four sedimentary profiles range between -0.31% and 0.34%, indicating that these four sedimentary profiles most likely record a single paleoflood event; the flood peak routing duration within the study reach is approximately 1.15 hours with attenuation of less than 1%, which aligns with the flood propagation characteristics of the study reach. This research holds significant scientific importance for understanding the routing patterns of extreme floods in the upper Han River, and provides fundamental data and scientific support for watershed flood design, flood forecasting, and flood control and disaster mitigation.

Full Text

Palaeoflood Research in the Yunxian Section of the Upper Hanjiang River During the Northern Song Dynasty

WANG Guang-peng, ZHA Xiao-chun, HUANG Chun-chang, PANG Jiang-li, ZHANG Guo-fang

School of Geography and Tourism, Shaanxi Normal University, Xi' an, Shaanxi, China

Abstract

Paleoflood hydrology represents a frontier discipline within global change research. Currently, most paleoflood studies focus on reconstructing water levels and discharges from single sedimentary profiles, while few have simulated paleoflood events using multiple sedimentary profiles across a river reach. This study investigates a paleoflood event from the Northern Song Dynasty based on four sedimentary profiles in the Yunxian reach of the upper Hanjiang River: Yanjiapeng (YJP), Shangjiahe (SJH), Guixianhekou (GXHK), and Mituosi (MTS). Using measured river cross-section data, hydrological parameters, and a designed paleoflood hydrograph, we employed the HEC-RAS model to simulate the flood routing and water surface profile. The simulated water levels at the four profiles showed errors between -0.31% and 0.34% compared with field-surveyed paleoflood stages, confirming the reliability of the HEC-RAS simulation. Furthermore, we designed a paleoflood hydrograph based on typical measured flood processes and simulated the unsteady flow routing of the Northern Song Dynasty flood. Results indicate that the flood peak traveled from the YJP to MTS profiles in approximately 1.15 hours, with less than 1% attenuation, consistent with the flood propagation characteristics of this reach. Visualization of inundation depth and flow velocity revealed that upstream depths exceeded downstream depths, while upstream velocities were lower than downstream velocities. Flood risk areas were concentrated within limited zones along both banks, constrained by the bedrock canyon morphology. This study provides fundamental data for flood design, forecasting, and disaster mitigation in the basin, offering significant scientific insights into catastrophic flood dynamics in the upper Hanjiang River.

Keywords: paleoflood research; Northern Song Dynasty; HEC-RAS model; flood prevention and mitigation; upper reaches of Hanjiang River

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1. Introduction

Flooding represents one of the most widely distributed and economically devastating natural disasters globally. Since the 21st century, the impacts of climate change on extreme hydrological processes have garnered widespread attention from meteorologists, hydrologists, and disaster risk researchers worldwide. UNESCO's International Hydrological Programme has identified extreme hydrological disasters as a key research priority in its second phase. Accurately simulating the propagation timing and movement patterns of extraordinary floods is crucial for understanding flood risks and formulating effective mitigation strategies.

The upper Hanjiang River, located in the climatic transition zone between northern and southern China, exhibits particularly significant hydrological responses to global climate change. Recent frequent flood events have not only severely impacted sustainable socio-economic development but also constrained the implementation of the Middle Route of the South-to-North Water Transfer Project. However, China' s hydrological observation records are relatively short, making it difficult to adequately understand flood occurrence patterns and establish reasonable flow-frequency relationships without data from paleofloods and historical floods.

Since the 1990s, Chinese scholars have conducted Holocene paleoflood investigations in major reaches of the Yangtze and Yellow Rivers, with results applied to major water conservancy projects. Professor Huang Chunchang has extensively investigated paleofloods in the upper Hanjiang River, reconstructing extraordinary flood events from geological records. Through compilation of recent research findings, we identified that four sedimentary profiles in the Yunxian reach—Yanjiapeng (YJP), Shangjiahe (SJH), Guixianhekou (GXHK), and Mituosi (MTS)—all record a paleoflood event from the Northern Song Dynasty (900 a BP; 1127 CE). Jin et al. [**?**] identified this as a catastrophic flood event in June 982 CE (Taiping Xingguo 7th year) through stratigraphic correlation and historical flood verification. This study employs the HEC-RAS model to simulate water surface profiles and flood routing for this event, providing fundamental data for flood risk assessment and mitigation.

2. Study Area and Flood Characteristics

The Hanjiang River originates at the southern foot of the Qinling Mountains and flows into the Yangtze River at Wuhan, with a total length of 1,577 km. This study focuses on the Yunxian reach of the upper Hanjiang River (Fig. [Figure 1: see original paper]). Field investigations confirm no major tributaries join this reach, which cuts through Paleozoic metamorphic rock formations, forming a bedrock canyon channel with an average width of 400 m. The region has a northern subtropical monsoon climate with an average annual precipitation of 1,000 mm. The Baihe hydrological station upstream controls a drainage area of 59,115 km^2 with a river length of 709 km. The historically investigated maximum flood occurred in 1583 CE with a peak discharge of 31,000 m$^3 \cdot$ s^{-1}, while the 2010 flood reached 34,800 m$^3 \cdot$ s^{-1}.

Due to its unique geographical location, topography, and atmospheric circulation, the upper Hanjiang River has experienced frequent catastrophic floods throughout history. Previous studies [**?**, **?**, **?**, **?**, **?**, **?**] indicate that floods in this reach are primarily transboundary events, with runoff generation concentrated in the Qinling and Micang mountain areas upstream of Ankang. For example, the extraordinary flood of June 1583 CE had storm centers in Xixiang, Shiquan, Ziyang, and Langao counties upstream of Ankang. Similarly, the 2010 flood' s storm centers were located in Nanzhang and Ziyang counties, both upstream of Ankang, with the Shiquan-above basin contributing 80% of the flood volume at the Ankang section.

3. Paleoflood Deposits from the Northern Song Dynasty in the Upper Hanjiang River

Paleofloods refer to flood events since the Holocene that were not directly observed or recorded. Current paleoflood research employs two methods: documentary records and geological evidence. While China has extensive historical documents, flood records often lack temporal continuity and quantitative detail, making geological records more reliable. Slackwater deposits (SWD), formed from suspended sediment during flood peak stages, accurately record hydraulic conditions and depositional environments, serving as the primary information carrier for paleoflood hydrology.

Field investigations in the Yunxian reach identified SWD in all four profiles dating to the Northern Song Dynasty (Fig. [Figure 2: see original paper]):

- **YJP Profile**: Located on the left bank near Yanjiapeng Village, with the top SWD layer being light brownish-yellow fine sand in a wedge shape pinching out toward the bank.
- **SJH Profile**: Located near Shangjiahe Village on the left bank, undisturbed with clear stratigraphy, containing SWD at 90 cm depth.
- **GXHK Profile**: Situated on the first terrace forefront, with the SWD layer clearly sandwiched between loess and topsoil layers, approximately 1.5 m above normal water level.
- **MTS Profile**: Located on the first terrace left bank, with turbid brown SWD wedge-shaped at 40 cm depth, 10 cm thick.

Stratigraphic correlation reveals that the top SWD layers in all four profiles date to 900 a BP (1127 CE), indicating a single extraordinary flood event. The deposits are concentrated within a 19 km stretch of bedrock canyon, with similar stratigraphic sequences. Previous research suggests this may record the catastrophic flood of June 982 CE (Taiping Xingguo 7th year).

4. HEC-RAS Model Construction

4.1 HEC-RAS Model Overview

The HEC-RAS model, developed by the U.S. Army Corps of Engineers (USACE), is widely used for river hydrodynamic analysis. Version 5.03 enables two-dimensional flood routing simulation [?]. This study employs its one-dimensional steady and unsteady flow modules to simulate the Northern

Song Dynasty paleoflood. The model is based on the energy equation and continuity equation:

Energy Equation:

$$Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e = Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g}$$

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0$$

Momentum Equation:

$$\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = \rho f_i - \frac{\partial P}{\partial x_i} + \lambda \frac{\partial^2 u_i}{\partial x_j \partial x_j}$$

Where: Y = flow depth (m), Z = elevation (m), V = average velocity ($\mathrm{m \cdot s^{-1}}$), α = kinetic energy correction coefficient, g = gravitational acceleration ($\mathrm{m \cdot s^{-2}}$), h_e = head loss (m), t = time (s), u = velocity ($\mathrm{m \cdot s^{-1}}$), P = pressure ($\mathrm{N \cdot m^{-2}}$), ρ = fluid density ($\mathrm{kg \cdot m^{-3}}$), λ = dynamic viscosity ($\mathrm{N \cdot s \cdot m^{-2}}$), x = distance between sections (m), and f_i = body force (N).

4.2 Model System Construction

4.2.1 River Cross-Section Data Field surveys using high-precision total stations and ArcGIS 1:10,000 topographic maps measured 22 river cross-sections uniformly distributed along the study reach (Fig. [Figure 3: see original paper]). The bedrock consists of Paleozoic metamorphic rock series [?], with stable valley morphology since the Holocene due to minimal tectonic activity and limited lateral migration.

4.2.2 Roughness and Contraction/Expansion Coefficients Manning' s roughness coefficient (n) is a critical sensitivity parameter. For this bedrock canyon reach with sparse vegetation, main channel $n = 0.035$ and bank $n = 0.045$. Contraction and expansion coefficients were set to 0.1 and 0.3 respectively, with flow regime specified as subcritical [?].

4.2.3 Boundary and Initial Conditions As catastrophic floods originate from storms in the Ankang-above region with no major tributaries in the study reach, lateral inflow was neglected. The upstream boundary at the YJP profile used a designed extraordinary flood hydrograph based on measured historical data, while the downstream boundary at the MTS profile used a stage-discharge relationship derived from measured cross-sections. Initial conditions were set to the multi-year average flow.

5. Results and Model Validation

5.1 Paleoflood Water Surface Profile Calculation

Due to the rarity of extraordinary floods in modern records, the 2010 flood ("2010.7" flood) was used for model validation. The simulated water levels showed good agreement with field survey flood marks, with errors between -0.18% and 0.32% (Fig. [Figure 4: see original paper]). The water surface profile paralleled the Northern Song Dynasty paleoflood profile, except for slight backwater near the MTS profile due to the Danjiangkou Dam.

Using the steady flow module with identical terrain and parameters, the paleoflood water surface profile was reconstructed (Fig. [Figure 4: see original paper]). Through iterative calibration, the optimal peak discharge was determined as 57,500 $m^3 \cdot s^{-1}$ [**?**], intermediate between previous reconstructions of 31,000–34,800 $m^3 \cdot s^{-1}$ [**?**, **?**]. Simulated water levels at the four profiles were: YJP = 178.10 m, SJH = 176.86 m, GXHK = 169.18 m, and MTS = 168.71 m, with errors of -0.31% to 0.34% compared to surveyed paleoflood stages (Table).

Table Simulation Error of Paleoflood Water Level at Four Sedimentary Sections

Profile	Surveyed Stage (m)	Simulated Stage (m)	Error (m)	Relative Error (%)
YJP	178.65	178.10	-0.55	-0.31
SJH	176.24	176.86	+0.62	+0.35
GXHK	168.60	169.18	+0.58	+0.34
MTS	168.35	168.71	+0.36	+0.21

5.2 Paleoflood Routing Simulation

Understanding flood movement patterns is crucial for forecasting, mitigation, and risk assessment. Using the unsteady flow module, the paleoflood routing was simulated based on a designed hydrograph scaled from the Baihe station's typical flood (Fig. [Figure 5: see original paper]). The flood peak traveled from YJP to MTS in approximately 1.15 hours, with less than 1% attenuation, consistent with flood propagation in bedrock canyons [**?**, **?**].

Visualization of inundation depth and velocity (Fig. [Figure 6: see original paper]) revealed: - Upstream depths (4–8 m) exceeded downstream depths (3–7 m) due to channel slope - Upstream velocities (3-6 $m \cdot s^{-1}$) were lower than downstream velocities (4–8 $m \cdot s^{-1}$) due to channel widening - Flood risk areas were concentrated within limited zones along both banks, constrained by the bedrock canyon morphology - Minimal flow loss occurred except at tributary mouths due to steep gradients and the "V"-shaped channel preventing extensive overbank flow

The simulated propagation time aligns with field observations that the 2010 flood peak traveled the same reach in 1.3 hours and historical records indicating 1.5 hours for similar events.

6. Conclusions

1) Compilation of recent paleoflood research reveals that four sedimentary profiles in the Yunxian reach (YJP, SJH, GXHK, MTS) record a paleoflood event from the Northern Song Dynasty (900 a BP; 1127 CE). Stratigraphic correlation indicates these profiles likely document a single extraordinary flood event, possibly the catastrophic flood of June 982 CE.
2) Using measured terrain data and the HEC-RAS steady flow module, the paleoflood water surface profile was reconstructed. The optimal peak discharge of 57,500 $m^3 \cdot s^{-1}$ produced simulated water level errors of -0.31% to 0.34% at the four profiles. Validation using the 2010 flood confirmed model reliability with errors of -0.18% to 0.32%. This demonstrates that the HEC-RAS simulation is scientifically sound and that the top SWD layers in the four profiles likely record a single Northern Song Dynasty flood event.
3) The unsteady flow module simulated paleoflood routing, showing the flood peak traveled from YJP to MTS in approximately 1.15 hours with less than 1% attenuation. Visualization revealed greater upstream depths but lower upstream velocities compared to downstream sections. The study highlights the need for enhanced flood monitoring and early warning systems to enable timely evacuation from high-risk areas along the riverbanks.
4) While Chinese paleoflood research has traditionally focused on single-profile reconstructions, this study demonstrates the value of multi-profile, reach-scale hydraulic modeling for understanding paleoflood dynamics. The methodology extends the record of extreme floods in the upper Hanjiang River and provides essential data for flood risk assessment and mitigation planning.

References

[?] ZHANG Guohong, ZHANG Dongfeng, ZHAO Yongqiang, et al. Changes of dry/wet surfaces in Shanxi Province under global warming[J]. Arid Land Geography, 2020, 43(2): 281-289.

[?] MA Aihua, YUE Dapeng, ZHAO Jingbo, et al. Spatiotemporal variation and effect of extreme precipitation in Inner Mongolia in recent 60 years[J]. Arid Zone Research, 2020, 37(1): 74-85.

[?] YIN Shuyan, HUANG Chunchang. Precipitation change and occurrence of rainstorms and floods in upper reaches of Hanjiang River during last 50 years[J]. Bulletin of Soil and Water Conservation, 2012, 32(1): 19-25.

[?] BAKER V R. Paleoflood hydrology: Origin, progress, prospects[J]. Geomorphology, 2008, 101(1-2): 1-13.

[?] THORNDYCRAFT V R, BENITO G. The Holocene fluvial chronology of Spain: Evidence from a newly compiled radiocarbon database[J]. Quaternary Science Reviews, 2006, 25(3-4): 223-234.

[?] SHEFFER N A, RICO M, ENZEL Y, et al. The palaeoflood record of the Gardon River, France: A comparison with the extreme 2002 flood event[J]. Geomorphology, 2008, 98(1-2): 71-83.

[?] GE Zhaoshuai, YANG Dayuan, LI Xusheng, et al. The paleoflooding record along the up reaches of the Changjiang River since the late pleistocene epoch[J]. Quaternary Sciences, 2004, 24(5): 555-560.

[?] WANG Zhaoduo, HUANG Chunchang, ZHA Xiaochun, et al. Palaeoflood sedimentological and hydrological study of the Luzhuang section in the upper reaches of Huaihe River[J]. Arid Land Geography, 2018, 41(2): 325-333.

[?] LI Xiaogang, HUANG Chunchang, PANG Jiangli. Palaeoflood events in the lower reaches of the Wudinghe River[J]. Arid Land Geography, 2020, 43(2): 380-387.

[?] JI Lin, PANG Jiangli, HUANG Chunchang, et al. Holocene palaeoflood studies of the Yanjiapeng reach in the upper Hanjiang River, China[J]. Advances in Earth Science, 2015, 30(4): 487-494.

[?] LIU Jianfang, ZHA Xiaochun, HUANG Chunchang, et al. Palaeoflood hydrological study in the Yun County reach in the upper reaches of the Hanjiang River[J]. Journal of Soil & Water Conservation, 2013, 27(2): 90-94.

[?] MAO Peini, PANG Jiangli, HUANG Chunchang, et al. The Holocene palaeoflood events at the Guixianhekou site in the Yunxi reach of the upper Hanjiang River[J]. Journal of Soil & Water Conservation, 2014, 28(2): 306-312.

[?] ZHENG Shuwei, PANG Jiangli, HUANG Chunchang, et al. Study on palaeoflood in Northern Song period at Mituosi segment of Hanjiang River, Hubei Province[J]. Journal of Natural Disasters, 2015, (3): 153-160.

[?] JIN Junfang, YIN Shuyan, WANG Xuejia, et al. Comparison of extraordinary flood events reflected selected by sediments with historical documents in the upper reaches of the Hanjiang River during the Chinese Northern Song Dynasty (950-1050 AD)[J]. Mountain Research, 2016, 34(3): 266-273.

[?] LIU Jiahui. Textual research on the extraordinary historical flood in Northern Song Dynasty in the upper reaches of Hanjiang River[D]. Xi’ an: Shaanxi Normal University, 2017.

[?] YANG Yongde, ZOU Ning, GUO Xiwang. Design flood analysis and calculation of Baihe hydrological station on Hanjiang River[J]. Journal of Water Resources Research, 1997, (3): 36-38.

[?] LI Wenhao. Hydrologic characteristics analysis in the upper reaches of Hanjiang River[J]. Journal of Water Resources and Water Engineering, 2004, 15(2): 54-58.

[?] LI Qingbao. Analysis of circulation characteristics of flood-causing rainstorm in Ankang[J]. Journal of Shaanxi Meteorology, 1991, (5): 10-14.

[?] LI Qingbao. Meteorological characters of the ten floods in upper reaches of Hanjiang River[J]. Journal of Catastrophology, 1991, (2): 43-48.

[?] HE Changchun. Preliminary study on some problems of extraordinary storm flood in the upper reaches of Hanjiang River[J]. Shaanxi Water Resources, 1985, (1): 43-50.

[?] WANG Xueqi. Characteristics of rainstorm and flood in upper reaches of Hanjiang River[J]. Shaanxi Water Resources, 1988, (1): 28-35.

[?] ZHANG Kai. Analyses of rainstorm and flood characteristics in the upper reaches of Hanjiang River[J]. Journal of Catastrophology, 2006, 21(3): 98-102.

[?] DANG Hongmei, ZHOU Yibing, LI Ding' an, et al. Synoptic analysis caused by disaster rainstorm in upper reaches of Hangjiang River[J]. Journal of Shaanxi Meteorology, 2011, (5): 14-17.

[?] HU Mingsi, LUO Chengzheng. China' s historical large floods[M]. Beijing: China Bookshop Press, 1989: 147-158.

[?] BAKER V R. Palaeoflood hydrology in a global context[J]. Catena, 2006, 66(1): 161-168.

[?] WEN Kegang. The ceremony Chinese meteorological disasters (Shaanxi volume)[M]. Beijing: China Meteorological Press, 2005: 44.

[?] GARY W. HEC-RAS River Analysis System Hydraulic Reference Manual[R]. U.S. Army Corps of Engineers, Davis, CA.

[?] ALHO P, BAKER V R, SMITH L N. Paleohydraulic reconstruction of the largest Glacial Lake Missoula draining(S)[J]. Quaternary Science Reviews, 2010, 29(23): 3067-3078.

[?] ZHANG Xingnan, PENG Shunfeng. Combined simulation system for propagation of flood in plain rivers and its application[J]. Journal of Hydraulic Engineering, 2010, 41(7): 803-809.

[?] WANG Baiwei, TIAN Fuqiang, HU Heping. Analysis of the effect of regional lateral inflow on the flood peak of the Three Gorges Reservoir[J]. Science China Technological Sciences, 2011, 41(7): 981-991.

[?] CHU Zhenda. The valley form of the upper Han River, from Pai-ho to Tan-chiang-kou[J]. Acta Geographica Sinica, 1955, 21(3): 259-270.

[?] Department of Hydraulics, Wuhan Institute of Water Conservancy and Electricity. Hydraulics[M]. Beijing: Higher Education Press, 1986: 335-336.

[?] HUANG Chunchang, PANG Jiangli, ZHA Xiaochun, et al. Prehistorical floods in the Guanzhong Basin in the Yellow River drainage area: A case study along the Qishuihe River Valley over the Zhouyuan Loess Tableland[J]. Scientia Sinica(Terrae), 2011, 41(11): 1658-1669.

[?] WAN H, HUANG C, PANG J. Major elements in the Holocene loess-paleosol sequence in the upper reaches of the Weihe River Valley, China[J]. Journal of Arid Land, 2016, 8(2): 197-206.

[?] BENITO G, THORNDYCRAFT V R. Palaeoflood hydrology and its role in applied hydrological sciences[J]. Journal of Hydrology, 2005, 313(1-2): 3-15.

[?] BENITO G, LANG M, BARRIENDOS M, et al. Use of systematic, palaeoflood and historical data for the improvement of flood risk estimation. review of scientific methods[J]. Natural Hazards, 2004, 31(3): 623-643.

[?] RAFF D. Appropriate application of paleoflood information for the hydrology and hydraulics decisions of the US Army Corps of Engineers[R]. USA: US Crops of Engineers, 2013.

[?] FENG Baofei, GAO Yuan, CHEN Yubin, et al. Coupling technology of hydrology and meteorology for forecast and regulation of flood of Danjiangkou Reservoir in July, 2010[J]. Yangtze River, 2011, 42(6): 41-44.

[?] SHEN Guihuan, LI Junshe. Analysis of the extraordinary storm flood in the upper reaches of Hanjiang River in July 2010[J]. Scientific & Technical Information of Gansu, 2011, 40(3): 66-67.

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