

Study on the Impact of Sandbar Evolution on Flood Control in the Jingjiang Reach of the Middle Yangtze River under New Water and Sediment Conditions

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Abstract: After the impoundment and operation of the Three Gorges Project, the water and sediment conditions in the middle and lower reaches of the Yangtze River have changed significantly, and the impact of sandbar evolution on flood control safety has become increasingly prominent. Taking the Jingjiang reach in the middle Yangtze River as the study area, this research investigates the evolution of sandbars and its impact on flood control under the new water and sediment conditions. The results show that, following the impoundment of the Three Gorges Reservoir, the evolution of sandbars exhibits several notable features: marked differentiation in erosion patterns at different elevations; erosion processes concentrated in the flood season; the growth and decline of sandbars strongly influenced by the release of clear water; and predominantly erosional trends on point bars. The impacts on flood control are manifested as follows: in meandering reaches, point bars on convex banks are dissected by momentum exchange between the main channel and the bar and by secondary reciprocating flow (e.g., at Tiaoguan), while point bars on concave banks are scoured by centrifugal forces (e.g., at Qigongling). In braided reaches, the stability of bar bodies decreases and mid-channel bars shrink (e.g., at Taipingkou). In straight transitional reaches, oblique inflow scours the toes of sandbars (e.g., at Wuguizhou). The evolution of sandbars triggers shifting of the main flow, weakens the river-regime control function, and leads to changes in flow impingement and near-bank scouring, thereby endangering levee stability and threatening regional flood control safety. In response, countermeasures are proposed, including strengthening the monitoring and early warning of sandbar evolution, accelerating the systematic treatment of riverbank collapse, improving the emergency protection system, establishing a long-term mechanism for emergency protection, and deepening research on sandbar evolution. The findings can provide scientific support for flood control, disaster reduction, and river management.

Keywords: new water and sediment conditions; Jingjiang reach ; sandbar evolution; flood control impact; countermeasures.

1. Introduction

The Yangtze River is the longest river in China with a mainstream length of approximately 6,300 km. Sandbars are extensively developed in its middle and lower reaches, where riverbed evolution is complex. With the successive completion of cascade reservoirs centered on the Three Gorges Reservoir in the upper Yangtze River and continuous improvement of the ecological environment, the sediment load transported from the upper reaches has decreased sharply. In 2019, the sediment discharges at Yichang, Shashi, Hankou and Datong Hydrological Stations dropped by 98%, 96%, 86% and 75% respectively compared with the period before the impoundment of the Three Gorges Reservoir [1]. The water and sediment conditions in the middle and lower reaches have thus undergone profound changes: the median grain size of suspended sediment has become finer, flood hydrographs have become more flattened, and the duration of medium flows has been markedly prolonged.

These changes have disrupted the original dynamic equilibrium of erosion and deposition of the riverbed in the middle and lower Yangtze River. As important components of the river system, sandbars have generally experienced erosion, retreat, and morphological reconfiguration under the dual influences of reduced sediment supply and persistently unsaturated flow. Such evolution not

only affects the stability of the river regime, but is also closely related to levee safety, bank stability, and flood conveyance capacity. In recent years, erosion of the Tiaoguan point bar, collapse of the point bar at the unrevetted section of Qigongling, and retreat of the Tianziyihao point bar in the Jingjiang reach of the middle Yangtze River have seriously threatened the safe operation of flood-control embankments.

To date, relatively limited research has been conducted either domestically or internationally on the impacts of sandbar evolution on flood control under new water and sediment conditions. Duan Wenzhong et al. [2] studied changes in the channel morphology of the Jingjiang reach following the construction of the Three Gorges Project. In 2007 and 2008, Duan Guanglei et al. [3, 4] investigated the impact of channel evolution in the Jingjiang reach on flood control and the mechanisms of typical sandbar evolution. In 2017, Raška P et al. [5] reported the disappearance of some fluvial islands downstream of a dam on the Elbe River in northern Czechia. In 2018, Lou YY et al. [6] analyzed the long-term evolution characteristics of mid-channel bars in the middle and lower Yangtze River based on satellite images. In 2020, Xu Zhaoming et al. [7] simulated the flood-control effects of channel erosion and deposition in the middle and lower Yangtze River. In 2021, Yang Xuhai et al. [8] explored the mechanisms of typical sandbar adjustment in the Lower Jingjiang reach. In 2024, Duan Guanglei et al. [9] studied the evolution characteristics and influencing factors of sandbars in the Jingjiang reach. The above studies have mainly focused on morphological changes, channel evolution, sandbar adjustment mechanisms, and evolution characteristics, with relatively little attention paid to the flood-control impacts of sandbar evolution under the new water and sediment regime. Therefore, it is of great practical significance to investigate the impact of sandbar evolution on flood control in the Jingjiang reach of the middle Yangtze River and to propose targeted countermeasures. Taking the Jingjiang reach as the research object, this paper analyzes the evolution characteristics of typical sandbars in three channel patterns—meandering, straight transitional, and braided—and their implications for flood control, thereby providing a scientific basis for flood control, disaster reduction, and river management in the middle and lower Yangtze River.

2. Overview of the Study Area

The Jingjiang reach in the middle Yangtze River extends from Zhicheng (Jing 3) in Hubei Province to Chenglingji (Jing 186) in Hunan Province, flowing through Zhijiang and Yidu in Yichang, Songzi, Jingzhou (District), Gong'an, Shashi (District), Jiangling, Shishou, and Jianli in Jingzhou, as well as Huarong and Yueyang in Hunan Province, with a total length of 347.2 km. It is divided by Ouchikou into the Upper and Lower Jingjiang. The Upper Jingjiang is 171.7 km long and exhibits a slightly curved, braided pattern; the Lower Jingjiang is about 175.5 km long and is a typical meandering river (Fig.1)[10].

The Upper Jingjiang consists of a curved channel formed by six bends—Yangxi, Jiangkou, Yuanshi, and others—with a smooth planform and stable configuration. Many mid-channel bars are found within the bends, such as Guanzhou in the Yangxi bend, Mayangzhou in the Yuanshi bend, Sanbatan in the Shashi bend, and Jinchengzhou in the Gong'an bend. There is the Tianxingzhou bar near Ouchikou, whose right branch diverts into Ouchikou and flows into Dongting Lake. After the artificial cutoffs, the Lower Jingjiang comprises 11 bends, including Shishou, Shatanzi, and Tiaoguan. Owing to bank revetment works and river-regime control, it has become a confined meandering channel. Except for the Jianli reach, where Wugui Island forms a braided reach, and the Zhongzhouzi reach, where Nanlianhua Island forms a braided reach, all other reaches are single-thread channels. Numerous point bars are distributed near the convex banks of the bends, such as the Xiangjiazhou point bar at the Shishou bend, the Nianziwan point bar downstream of Shishou, the Liuhejia and Xiasanheyuan point bars in the vicinity of Shatanzi–Tiaoguan, and the Wuguizhou point bar at Jianli.

The Zhicheng–Dabujie subreach of the Jingjiang has a gravel–sand bed with gravel and pebble bars, and the lateral migration of the thalweg is relatively small. The Dabujie–Ouchikou subreach has a sandy bed. In the bed material of the Upper Jingjiang, the proportion of medium sand (0.25–0.50 mm) is higher than that in the Lower Jingjiang, whose bed is mainly composed of fine sand (0.10–0.25 mm) [1]. Regarding grain-size variation, the bed material in the Upper Jingjiang becomes finer downstream with a large gradient, whereas in the Lower Jingjiang the variation is generally small and the gradient gentle. After the impoundment and operation of the Three Gorges Reservoir, the bed material has coarsened, and the gravel-bed reach has extended downstream. The coarsening is mainly reflected by an increase in the fraction of particles larger than 0.125 mm.

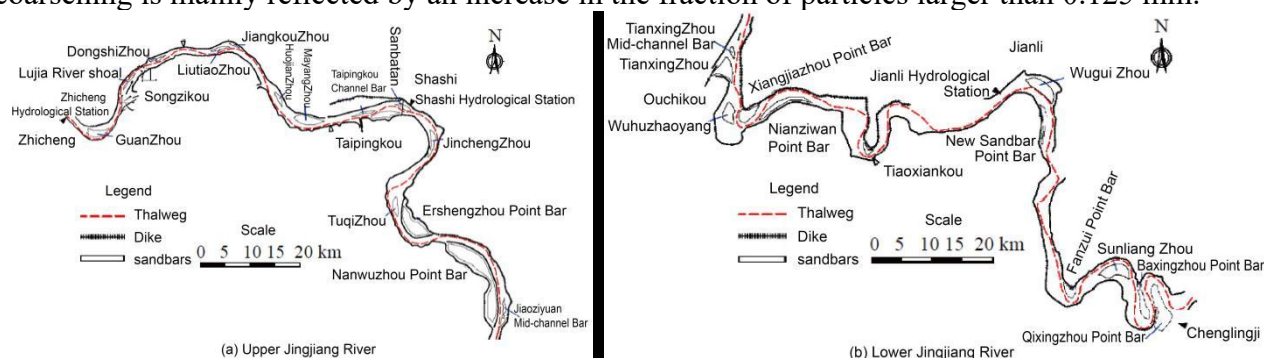


Fig.1 River regime map of the Jingjiang reach

3. Impact of Sandbar Evolution on Flood Control

3.1 Main Characteristics of Sandbar Evolution

Since the impoundment of the Three Gorges Reservoir, the number of mid-channel bars and shoals that have shrunk in area in the middle and lower Yangtze River is relatively large, and the shrinkage is more pronounced in the reach above Chenglingji; the contraction of mid-channel bars in the lower reach has lagged behind that in the middle reach. For bars with relatively high elevation, erosion generally starts at the bar head, causing the low-elevation part of the head to shrink, and then gradually extends toward the center of the bar. The side of the bar adjacent to the main branch is more susceptible to undercutting, while the bar tail remains essentially stable. For low-elevation mid-channel bars and submerged bars, the evolution is characterized by overall erosion of the bar body, lowering of the bar surface, and downstream migration of the entire bar. Erosion of sandbars occurs mainly during flood seasons with high discharge and high water levels. In most slightly curved and straight braided reaches, the long axes of mid-channel bars are generally aligned with the flow direction, and their growth or shrinkage is directly related to the incoming flow and sediment load, being relatively strongly influenced by the release of clear water. The evolution of mid-channel bars in goose-head-type braided reaches is also affected by protruding bedrock outcrops. Point bars generally experience dominant erosion, with noticeable bar scouring, chute cutoff, and bend bypassing in sharply curved reaches. In straight reaches, point bars on convex banks are eroded while the channel at concave banks experiences deposition. Erosion and dissection of floodplains also occur.

(1) Upper Jingjiang

After the impoundment of the Three Gorges Reservoir, the riverbed of the Upper Jingjiang has undergone intense scour, resulting in significant changes in channel morphology. The river regime has adjusted considerably, and the channel has become increasingly unstable. In the Guanzhou braided reach of the Zhijiang section, the left branch has been developing, exhibiting a tendency for the main and secondary branches to swap positions. The right branch (Shihong) of the Lujiahe mid-channel bar has scoured and widened the bank of the Shangbailizhou bar on the right bank.

The most pronounced changes in the river regime of the Upper Jingjiang have occurred in the Shashi section, particularly in the zone from the Taipingkou mid-channel bar to the Sanbatan

braided reach. For example, the Taipingkou mid-channel bar has experienced substantial erosion and deposition. Before 2008, it progressively aggraded and migrated downstream year by year, whereas after 2008, it has gradually eroded, shrunk, and been dissected. The Sanbatan bar has been scoured, leading to a lowering of its surface elevation; the bar body has shrunk, disintegrated, and shifted, remaining in a state of intense adjustment. In the Jinchengzhou braided channel, the left branch serves as the main channel and is relatively stable, while the right branch has been scoured deeper, gradually transforming into a mid-channel bar. The surface elevation of this bar has been lowered by scour, and the bar body has shrunk and been dissected.

From the bend at the end of the Gongan Reach, through the transitional section from Yangjiachang to Qijiayuan, and up to the Haoxue bend, the main flow scouring tends to deviate from the concave banks. The heads of the bars in the braided reaches and the side of the bar bodies facing the main channel have also experienced scouring and collapse to varying degrees.

(2) Lower Jingjiang

After the impoundment of the Three Gorges Reservoir, in the Lower Jingjiang, the flow has shown a tendency to straighten and its impingement points to shift downstream, regardless of whether the reach is an excessively curved sharp bend (e.g., Tiaoguan, Qigongling), an ordinary meandering bend (e.g., the new Zhongzhouzi cutoff channel, Jingjiangmen, Guanyinzhong), a long slightly curved reach (e.g., Luxiwan, Wumakou–Tashiya), a straight transitional reach between opposite bends (e.g., Zhongzhouzi–Egongtu, Puziwan–Tianziyihao), or a straight reach between bends of the same direction (Yanchuantao). This has resulted in scour of point bars on convex banks, deposition in the channel along concave banks, as well as widening and deepening of the channel in slightly curved and straight reaches. In addition, bar scouring, bar dissection, and bend bypassing (chute cutoff) phenomena are more pronounced in meandering sections.

The slightly curved sections largely maintain their original planform morphology, but they also exhibit a tendency toward straightening as their channels widen. Erosion and dissection of floodplains have also occurred.

In the meandering sections of the Lower Jingjiang, except for the Jianli bend where the impingement point shifted upstream, the impingement points in the other nine meandering bends all shifted downstream to a certain extent. The intra-annual variation of the thalweg planform position in meandering sections is characterized by *the main flow tending to occupy the central part and straighten during flood seasons, while moving toward and following the concave bank downstream during medium and low flow periods*. The convex point bars in bends such as Lianxinyuan–Tiaoguan, Zhongzhouzi, Jianli, Qigongling, and Guanyinzhong have exhibited bar dissection and bend bypassing phenomena to varying degrees.

3.2 Impact of Sandbar Evolution on Flood Control

Three typical reaches of the Jingjiang river — meandering, braided, and straight transitional — are selected to analyze the impact of sandbar evolution on flood control.

3.2.1 Meandering reaches

(1) Erosion of point bars on convex banks

In meandering channels, the point bar on the convex bank and the main channel are closely coupled and interact with each other, making the water and sediment transport highly complex. During medium and low flow seasons, the meandering channel conveys flow mainly through the main channel, with the flow aligning smoothly and meandering downstream. When a flood arrives, the discharge is large and changes rapidly, causing the water level to rise steeply and inundate the point bar on the convex bank. After the flow overtops the bar, the flow structure changes markedly as the cross-sectional shape is altered. The two currents over the bar and in the main channel interact intensely, producing distinct momentum exchange between the bar and the channel and secondary reciprocating flow phenomena. At the same time, the overbank flow provides the driving force for lateral sediment transport, influencing the exchange of mass and energy in the meandering

channel and causing complex changes in the erosion and deposition of the point bar and the main channel.

Since November 2008, the point bar on the convex bank of the Tiaoguan bend (its upper part) has been eroded and dissected, and the plane position of the main current at the bend entrance cross-section has shifted leftward (Fig.2). This has played a significant role in adjusting the near-bank erosion and deposition pattern in the Tiaoguan reach, markedly reducing the flow-deflecting effect of the Tiaoguan rock outcrop. The scour hole at the Tiaoguan protrusion has largely filled in, becoming smaller and shallower. During high-water flood seasons, the flow pattern around the Tiaoguan protrusion is highly complex. The compression of flow lines by the low-water protrusion causes a sharp increase in velocity over the protrusion platform, generating a horizontal-axis circulation above the platform. This circulation combines with the vertical circulations at the upstream and downstream edges of the protrusion to form a spiral flow pattern with stronger erosive power. The near-bank deep channel at Tiaoguan experiences considerable erosion during flood seasons, making this section a key defense point for the Jingnan Yangtze main levee.

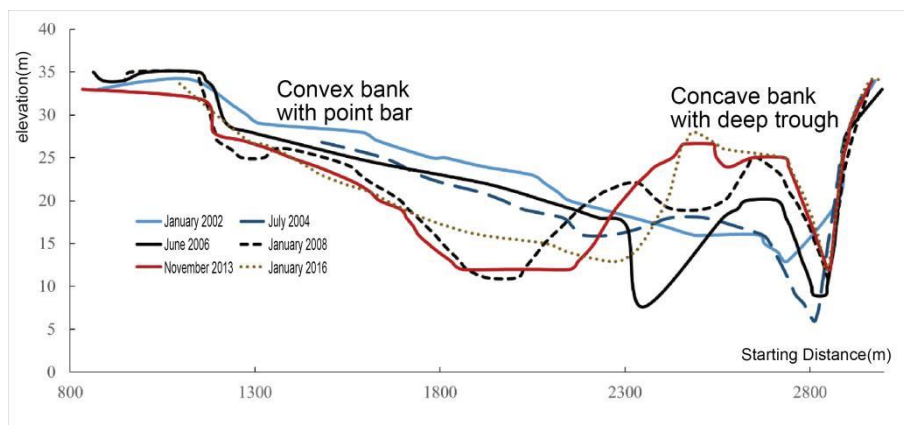


Fig.2 Cross-sectional changes at the entrance the Tiaoguan bend (elevation 30 m)

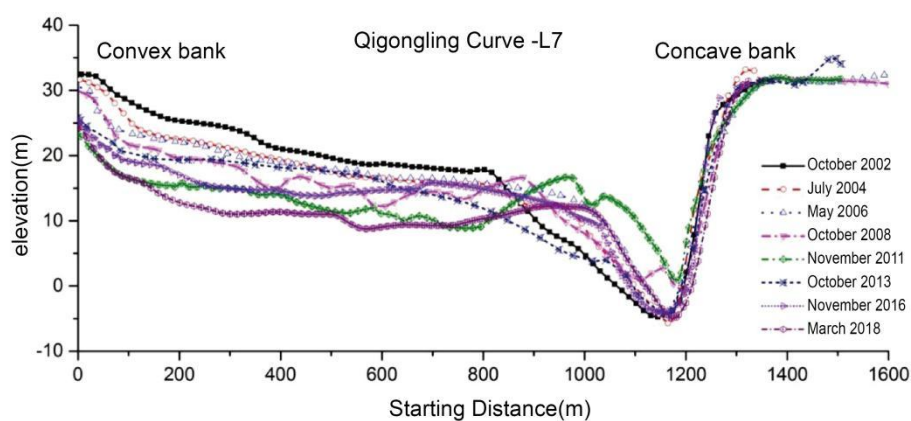


Fig. 3 Typical cross-sectional changes near of the Qigongling bend

(2) Erosion of bars on concave banks

The flow structure in meandering channels is characterized by typical helical flow. Under the action of centrifugal force, the surface flow moves toward the concave bank, while the near-bottom flow moves toward the convex bank, transporting sediment to the point bar on the convex bank [8]. As a result, the bar on the concave bank is susceptible to erosion and collapse. Before the construction of the Three Gorges Reservoir, under the backwater effect from Dongting Lake during flood seasons and the falling water levels during dry seasons, the point bars in the Lower Jingjiang generally followed a pattern of one-way progradation and widening—*deposition during floods and no erosion during low flows*. The growth of point bars and the retreat of concave banks proceeded at comparable rates, and the interannual longitudinal erosion and deposition of the Lower Jingjiang

channel remained relatively balanced. After the impoundment, the sediment supply decreased drastically, and the duration of medium flows lengthened. With moderate overbank water depths, the velocity difference between the bar and the channel reached its maximum, shear turbulence became the strongest, and lateral sediment transport intensified, resulting in an imbalance between the erosion of point bars on convex banks and the retreat of concave banks.

The concave banks of meandering reaches, where the main current impinges, are often hazardous sections for flood control. Since the impoundment of the Three Gorges Project, the Qigongling bend has experienced marked river regime adjustments, with the impingement point shifting downstream significantly. The lower part of the concave bank at Qigongling has undergone substantial near-bank riverbed erosion, and the unrevetted bankline has collapsed severely (Fig. 3), threatening the flood-control safety of the Yueyang Yangtze main levee. Analysis of measured topography of the lower Qigongling reach reveals that from May 2006 to December 2019, the near-bank riverbed in the lower section (chainage 14+050–18+450) was severely eroded, with an average erosion of 18.79 m at the toe of the underwater slope.

3.2.2 Braided reaches

Since the impoundment of the Three Gorges Project, the total incoming water volume has changed little, while large flood peaks have been reduced to some extent and the duration of medium flows has increased. Analysis of observed data indicates that in sandy braided channels, low erosion resistance leads to inherently poor bar-channel stability. A reduction in sediment supply will then inevitably cause a further decline in bar stability and an increased likelihood of bar erosion and dissection. Erosion during large floods is mainly concentrated at the low-elevation bar head and on the concave-bank margin of the shorter branch channel. After large floods, the shorter branch tends to undergo obvious erosion and widening. If subsequently subjected to low flows, local deposition shoals may form within the shorter branch due to flow dispersion. Under the new water and sediment regime, the shorter branch of a braided channel has a favorable development tendency because of its lower resistance. In particular, the prolonged duration of medium flows significantly lengthens the time during which the main current flows through the branch along the convex bank, thereby greatly increasing the probability of its erosional development.

The Taipingkou mid-channel bar is located at Taipingkou in the Shashi reach. From 2003 to 2018, the bar was significantly eroded, with a maximum scouring depth exceeding 5 m. The head of the bar retreated considerably, while deposition occurred at the tail of Lalinzhou. The south branch of Sanbatan developed through erosion, and the entrance of the north branch experienced deposition. Meanwhile, the natural bank slope of the upper Lalinzhou section collapsed severely. As the Taipingkou mid-channel bar shrank markedly, its role in controlling the river regime during medium and low flow periods weakened, making the river regime in this reach unstable to some extent and adversely affecting the stability of downstream reaches and the safety of flood-control works.

From the cross-sectional changes (Fig.4), the thalweg was located near the left bank in 1998 and 2002, then gradually shifted toward the right channel. Since 2004, the thalweg has been basically in the right channel, although with considerable fluctuations. From 2004 to 2011, the thalweg experienced a cumulative leftward shift of up to about 280 m. From 2011 to 2018, the thalweg swung back and forth laterally. In October 2018, it shifted to a position close to that of November 2013, and the deepest point had been scoured approximately 2.7 m deeper than in November. In terms of overall channel change, the riverbed underwent cumulative erosion and incision from October 1998 to October 2018, with the bankfull cross-sectional area increasing by 20.9% and a cumulative average bed erosion of 1.0 m.

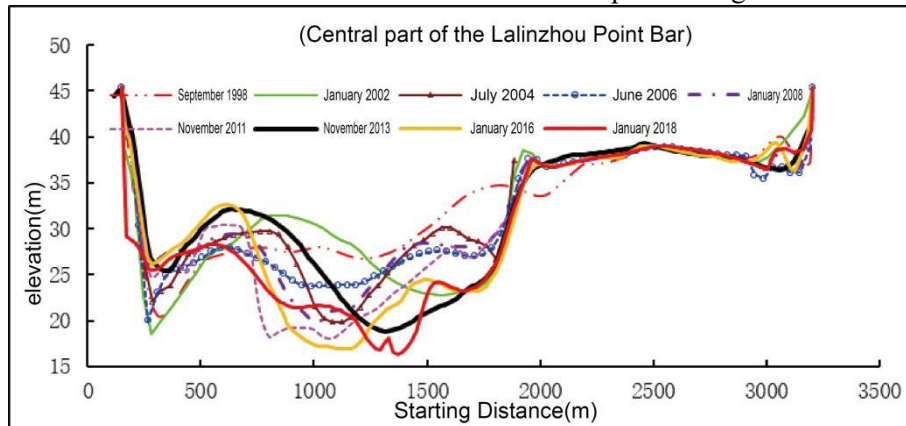


Fig.4 Typical cross-sectional change at the middle part of the Lalinzhou point bar

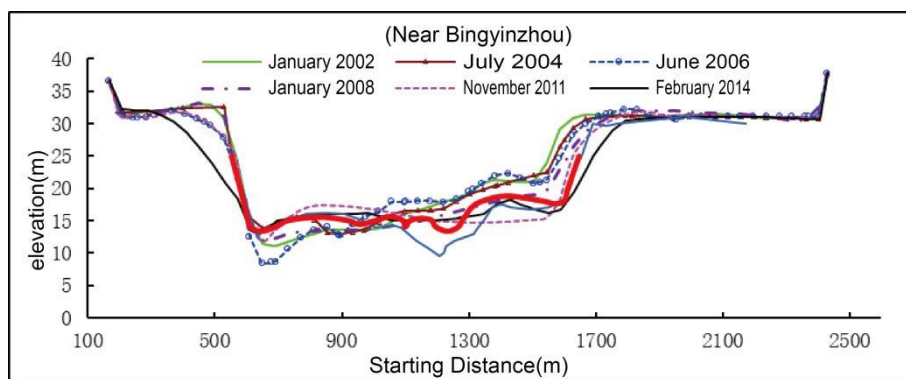


Fig.5 Typical cross-sectional changes near Bingyinzhou

3.2.3 Straight transitional reaches

Straight transitional reaches are the connecting sections between one meandering bend and the next. Their planform is relatively straight, but point bars and mid-channel bars are often developed on the riverbed. Generally, the flow exiting an upstream bend enters the straight reach at a certain angle, forming an oblique inflow that increases near-bank velocities. When large discharges occur, overbank flow usually takes place. After inundating the bar, due to the velocity difference and interaction between the bar and channel flows, momentum exchange occurs, generating vertical vortices at the bar–channel interface. A spiral flow develops in the main channel, promoting lateral sediment exchange [11] and easily scouring the toe of the bank slope.

The Wuguizhou high-elevation bar is located in the straight transitional reach of the Jianli channel. Since the impoundment of the Three Gorges Project, the main flow has consistently taken the right branch of Wuguizhou. However, after the low-elevation part of the bar head was washed away, the entrance to the bifurcation became excessively wide, causing the thalweg at the entrance to swing significantly, with a maximum amplitude of up to 1,050 m. In October 2008, the location where the main current impinges on the right margin of Wuguizhou shifted upstream by about 4.5 km compared to 2008. From 2008 to 2018, the thalweg at the entrance of Wuguizhou changed little. The main flow entered the Jianli bend along the right bank, gradually shifted toward the right bank near the upstream of Xinshazhou, and then traveled downstream along the right margin of Wuguizhou. With the head retreat of the bar and changes in upstream sediment supply, the right margin of Wuguizhou also retreated year by year. Consequently, the main flow in the right branch progressively shifted leftward, causing the impingement point where the outflow from the tail of Wuguizhou attacks the downstream left bank to migrate upstream year by year to Taiheling, where some bank retreat occurred.

Affected by the gradual upstream migration of the impingement point near Taiheling, the main current in the downstream reach has been shifting rightward year by year, causing continuous

erosion of the Bingyinzhou point bar on the right bank. The thalweg has accordingly swung to the right. The main current then transitions from the left bank at Shajiabian–Damazhou toward the right bank at Tianziyihao, seriously threatening the safety of the Yueyang Yangtze main levee.

From the cross-sectional changes (Fig.5), in 1998 the cross-section had a left-skewed *V* shape, which gradually transformed into a *U* shape and has basically maintained this form to the present. Initially the thalweg leaned toward the left bank, as the right-side bar was continuously eroded and retreated, the thalweg swung rightward after 2008. Since October 2016, the thalweg has shifted markedly to the right, with clear erosion in the middle part of the section. By October 2018, the thalweg had leaned toward the left bank again. Since 1998, the cross-section has experienced cumulative erosion, the bankfull area has increased, and the cumulative average erosion depth is 5.1 m. The cumulative scour in the deep channel is not significant, manifested mainly as bed deepening near the right bank of Bingyinzhou. This near-bank erosion will have adverse effects on bank slope stability.

4. Countermeasures

In response to the flood control problems caused by the above-mentioned sandbar evolution, the following countermeasures are proposed.

4.1 Strengthen Monitoring and Early Warning Of Sandbars

Reinforce observations of channel topography, fixed cross-sections, river-regime changes, and local channel conditions in bank collapse sections of the Jingjiang reach. Increase the frequency of inspections and monitoring, especially in accident-prone sections such as Tiaoguan, Qigongling, and Beimenkou. Make full use of new methods, instruments, and technologies to further enhance emergency monitoring capabilities for bank collapses of sandbars. Establish criteria for assessing bank collapse risk levels, strengthen the operation of the riverbank collapse warning system, and achieve equal emphasis on monitoring, analysis, and early warning of riverbank collapses.

4.2 Accelerate Systematic Treatment of Riverbank Collapse

In light of the new situations and characteristics of channel evolution since the impoundment of the Three Gorges Reservoir, evaluate the adaptability of river regulation works, optimize node control schemes for river-regime management, and carry out systematic treatment that couples river-regime control measures. Fully summarize the scientific research achievements from the 14th Five-Year Plan period, make preliminary preparations for the implementation of comprehensive river regulation projects during the 15th Five-Year Plan period, and actively advance the preliminary work and project implementation of the Three Gorges Follow-up Work Implementation Plan (2026–2035). Accelerate the progress of key river regulation projects currently under construction in the Jingzhou section and initiate bank collapse treatment at Qixingzhou in the Lower Jingjiang, thereby providing favorable conditions for sandbar evolution.

4.3 Improve the Emergency Protection System For Sandbar Bank Collapses

Clarify and implement the primary responsibility of local governments for emergency protection and remediation of bank collapses, enhance their initiative in bank collapse remediation, designate specific responsible personnel, organize emergency response teams, stockpile sufficient emergency materials, formulate emergency plans, and strengthen monitoring and defense. Strictly enforce the duty and shift responsibility system, promptly respond to sudden bank collapse hazards of sandbars, and immediately take emergency measures to address problems when they are still small and at an early stage, so as to ensure engineering safety.

4.4 Establish a Long-Term Mechanism for Emergency Bank Collapse Protection

Given the suddenness and high destructiveness of bank collapses along the Yangtze River, establish an emergency protection mechanism and a dedicated funding channel for emergency bank collapse protection. Studies could explore using state financial funds, the Yangtze Green Development Fund, or a certain proportion of the incremental electricity generation revenue of the Three Gorges Project beyond the designed multi-year average to set up an emergency protection fund for bank collapses. On this basis, establish a long-term emergency protection mechanism that integrates monitoring and early warning, material reserves, and the principle of *emergency repair first and compensation later*, so as to detect and effectively handle dangerous situations in a timely manner, maintain river-regime stability, and ensure flood-control safety.

4.5 Deepen Research on Key Technologies Related to Sandbars

Further strengthen research on the laws of channel erosion and deposition under new water and sediment conditions, improve the accuracy and capability of mathematical model predictions, ascertain the medium- and long-term erosion–deposition trends and river-regime change characteristics of the middle and lower Yangtze River after the operation of the upstream cascade reservoirs, and conduct in-depth analysis of their impacts on sandbar evolution and flood control. Continuously enhance research on the mechanisms of sandbar bank collapse, perceptual screening, three-dimensional monitoring, predictive simulation, graded early warning, and systematic prevention and control. Develop an integrated bank collapse monitoring, early warning, and management system that merges *intelligent perception – bank slope monitoring – prediction and early warning*, so as to substantially raise the level of bank collapse prevention and control.

5. Summary

(1) After the impoundment of the Three Gorges Reservoir, a relatively large proportion of mid-channel bars and shoals in the middle and lower Yangtze River have decreased in area, especially in the reach above Chenglingji. Erosion patterns vary with bar elevation: high-elevation bars experience initial erosion at the head, which gradually extends toward the central part, and the side adjacent to the main branch is prone to undercutting; low-elevation bars undergo overall erosion, lowering of the bar surface, and downstream migration. However, erosion of sandbars occurs mainly during high-discharge, high-water-level flood seasons. The growth and decline of sandbars in slightly curved and straight braided reaches are significantly influenced by the incoming flow and sediment load and by clear water release; goose-head-type braided reaches are also affected by rock outcrops. Point bars generally experience dominant erosion, but different channel patterns display distinct erosion and deposition characteristics.

(2) After the impoundment of the Three Gorges Reservoir, the general erosion of sandbars in the Jingjiang reach has impacted flood control. In meandering reaches, when floods inundate point bars on convex banks, interactions between bar and channel flows produce marked momentum exchange and secondary reciprocating flow, leading to erosion and dissection of the Tiaoguan point bar. For concave-bank bars, centrifugal force drives the surface flow toward the concave bank and transports sediment with the near-bottom flow toward the convex bank, resulting in substantial erosion of the near-bank riverbed in the lower concave-bank section of the Qigongling bend. In braided reaches, bar stability decreases and the likelihood of bar erosion and dissection increases, as exemplified by the marked shrinkage of the Taipingkou mid-channel bar. In straight transitional reaches, flow from the upstream bend typically enters at an angle, creating oblique inflow and higher near-bank velocities; at larger discharges, vertical vortices form at the bar–channel interface and spiral flow develops in the main channel, easily scouring the toe of the bank slope, as seen in the year-by-year retreat of the right margin of Wuguizhou. Sandbar evolution triggers shifts in the main current, weakens the river-regime control function, and leads to changes in impingement locations and

concentrated near-bank erosion, ultimately posing a prominent challenge to the stability of bank levees and flood-control safety.

(3) To reduce the flood control impacts of sandbar evolution, it is necessary to strengthen monitoring and early warning, accelerate systematic treatment of riverbank collapse, improve the emergency protection system, establish a long-term emergency protection mechanism, and deepen research on key technologies related to sandbars.

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