

The impact of river-lake flow and sediment exchange on sediment scouring and siltation in middle and lower Yangtze River

Y Liu^{1,2}, Z L Wang¹ and L Q Zuo¹

1. State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing, China;

2. Hohai University, Nanjing, China

Abstract. The operation of TGR (Three Gorges Reservoir) caused river erosion and water level decline at downstream, which affects the water and sediment exchange of river-lake (Yangtze River – Dongting lake & Poyang lake). However, the change of river-lake relationship plays a significant role in the flow and sediment process of Yangtze River. In this study, flow diversion ratios of the three outlets, Chenglingji station, Hukou station are used as indexes of river-lake exchange to study the response of river erosion to flow diversion ratios. The results show that:(1) the sediment erosion in each reach from Yichang to Datong has linear correlation with the flow diversion ratio of the three outlets; (2) the sediment erosion above Chenglingji has negative linear correlation with the flow diversion ratio of Chenglingji station. While the sediment erosion below Chenglingji station has non-linear correlation with the flow diversion ratio variation of Chenglingji station; (3) the reach above Hankou station will not be affected by the flow diversion ratio of Hukou station. On one hand, if the flow diversion ratio is less than 10%, the correlation between sediment erosion and flow diversion ratio of Hukou station will be positive in Hankou to Hukou reach, but will be negative in Hukou to Datong reach. On the other hand, if the flow diversion ratio is more than 10%, the correlation will reverse.

1. Introduction

There are many lakes located in the middle and lower reaches of the Yangtze River, including the two largest freshwater lake in China, namely Dongting lake and Poyang lake. The water and sediment in the Yangtze River fall into Dongting lake through the three outlets (Songzi outlet, Taiping outlet and Ouchi outlet). Meanwhile, Dongting lake accept the runoff from Xiang river, Zi river, Yuan river and Li river and then afflux into Yangtze River through Chenglingji hydro-junction. While Poyang lake gather the runoff from Xiu river, Fu river, Rao river, Xin river and Gan river and then afflux into Yangtze River via Hukou station (Figure 1). The relationship between Yangtze River and the two lakes is complicated, due to the complex process of the water and sediment exchange between them.

After the operation of the TGR (Three Gorges Reservoir), spatial and temporal distribution of downstream water and sediment make a difference comparing to the natural conditions. Above all, the greatly decrease of sediment influence the relationship between Yangtze River and the two lakes and the erosion and deposition characteristics of Yangtze River significantly (Hu et al. 2014). As the most important hydro-junction, the influence of TGR to downstream river and lake receives much attention for a long period of time and has produced fruitful achievements.

Since the operation of TGR, the original relative equilibrium of river erosion and deposition has been broken, and the river bed condition transferred from “channel erosion, beach deposition” into “channel



and beach erosion” (Xu et al. 2013). Annual erosion mass of Yichang to Hukou reach was about 0.12 billion m^3 , and the main scouring region was Jing river (Lu et al. 2006). Sediment discharge of Yichang station has decreased by 90%, while the sediment discharge of Hankou and Datong station displayed a decreasing tendency which is obvious in flood season, and sand excavation should be considered in the sediment discharge calculation (Wang et al. 2014, Wang et al. 2014, Ban et al. 2014).

The water and sediment transport in Dongting lake and Poyang lake has been affected by the operation of TGR as well. The discharge of Chenglingji station has increased, while the water volume of Dongting lake has decreased (Xu 2013, Fang et al. 2013). The deposition inside Dongting lake has decreased significantly, and the annual deposition mass has decreased by 93% (Zhu et al. 2014, Huang et al. 2011). The impounding operation of TGR at the end of flood period results in the 0.4~1.6 m decrease of Hukou water level, which leads to 0.3~1.2 m decrease of water level inside Poyang lake (Zhu et al. 2014, Xu et al. 2013).

As to the three outlets, research indicated that flow and sediment diversion ratios of the three outlets has decreased slightly since the operation of TGR, and the downstream channel of the three outlets turn a silting situation into a scouring one (Cao et al. 2015, Li et al. 2009, Zhu et al. 2016).

However, there are few researches about the influence of variation of river-lake relationship to river erosion and deposition in Yangtze River. A regression equation between the annual sediment deposition in the Yichang to Hankou reach and the annual average suspended sediment concentration at Yichang station is established in 1980-1997, which relates the annual sediment deposition in the Yichang to Hankou reach and the ratio of the flow diverted through the three outlets (Xu 2006). Based on the observed data analysis, the research results show that the flow and sediment diversion of the three outlets make contribution to the deposition of Yangtze River (Hu et al. 2016). While the influence of three outlets’ diversion to sediment transport in the lower Yangtze River and the influence of Chenglingji and Hukou’ diversion has not been considered in the above researches.

Therefore, a one-dimension river-lake water and sediment numerical model was established in this paper. Flow diversion ratios of the three outlets, Chenglingji station, Hukou station are used as indexes of river-lake exchange to calculate the river erosion distribution in Yangtze River. The response of river erosion to flow diversion ratios was also analyzed.

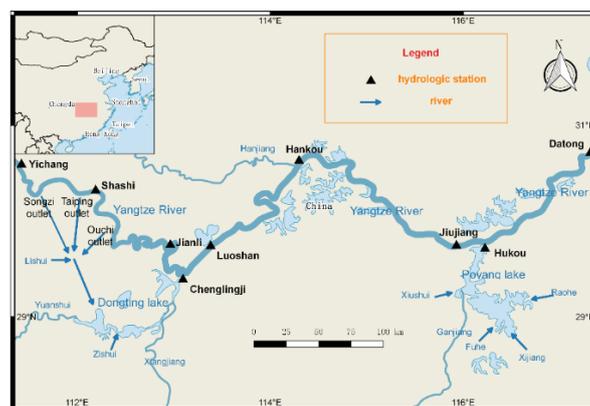


Figure 1. Schematic diagram of the main water system in middle and lower Yangtze River

2. The one-dimension river-lake water and sediment numerical model

The model calculates from Yichang station to Datong station composed of 1540 calculation profile, and the total calculation distance is 1190 km (figure 2). Yichang station is located at the junction of upper and middle Yangtze River, representing the water-sediment characteristic of released flow from TGP. While Datong station is located in lower Yangtze River, representing the tidal limit of Yangtze River estuary. The runoff of Dongting lake, Hanjiang river and Poyang lake are considered as important water-sediment boundary conditions in this model.

Based on the observed water-sediment data in 2003-2013, water and sediment process from Yichang to Datong are verification. Water and sediment discharge of Yichang station is adopted as inlet discharge, and the stage-discharge relation of Datong station in 2003-2013 is used as outlet boundary condition. The flow and sediment process verifications (figure 3 and table 1) shows that the model could simulate the water and sediment transport process in middle and lower Yangtze River accurately.

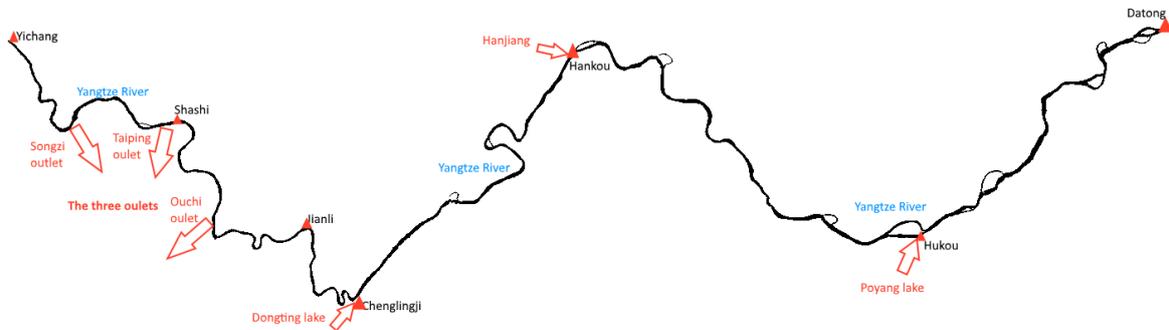


Figure 2. Schematic diagram of the water-sediment numerical model from Yichang to Datong

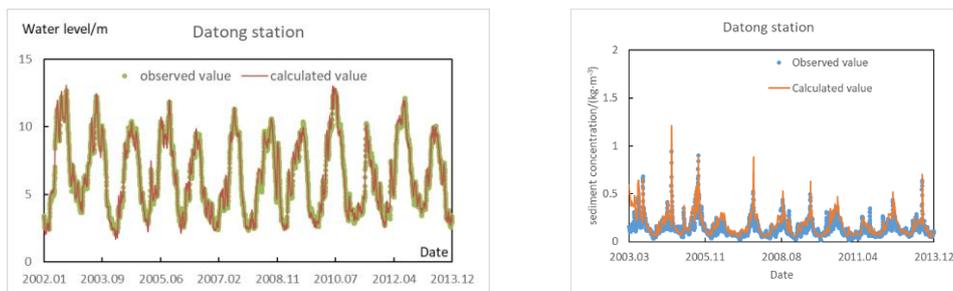


Figure 3. The verification of water level and sediment concentration process in 2003-2013

Table 1. Verification of scouring and siltation volumes/ (hundred million m³)

Region	Reach	Observed	Calculated	Deviation
Yichang-Chenglingji	Yichang - Dabujie	-1.46	-1.19	19%
	Dabujie - Ouchi outlet	-2.05	-0.81	61%
	Ouchi outlet - Chenglingji	-2.00	-0.83	58%
	Total(sand excavation not considered)	-5.51	-2.83	49%
	Total(sand excavation considered)	-3.20	-2.83	12%
Luoshan-Wuxue	Luoshan-Shijitou	0.34	-0.16	147%
	Shijitou-Hankou	-0.60	-0.27	55%
	Hankou-Wuxue	-1.47	-0.49	67%
	Total(sand excavation not considered)	-1.73	-0.92	47%
	Total(sand excavation considered)	-1.07	-0.92	14%

* “-” represents for erosion, “+” represents for deposition

3. The response regularity of river erosion and deposition to flow diversion ratios

Flow diversion ratios of the three outlets, Chenglingji station, Hukou station are used as indexes to represent the water-sediment exchange of river-lake. Therefore, the change of indexes will result in variation of sediment erosion and deposition distribution in Yangtze River.

3.1. Calculation scheme

The indexes can be set as different values by adjusting the corresponding boundary conditions in the model. (table 2)

Table 2. Calculation scheme

Project name	Project instruction	Average flow diversion ratio
Current situation	The observed data	9.7%, 38.5%, 17.0% (Three outlets, Chenglingji, Hukou)
Three outlets 2.0	The discharge of three outlets increases by 100%	18.0%
Three outlets 1.5	The discharge of three outlets increases by 50%	14.0%
Three outlets 0.5	The discharge of three outlets decreases by 50%	5.1%
Three outlets 0	The three outlets block off, discharge decreases by 100%	0%
Chenglingji 2.0	The discharge of Chenglingji increases by 100%	56.0%
Chenglingji 1.5	The discharge of Chenglingji increases by 50%	48.0%
Chenglingji 0.5	The discharge of Chenglingji decreases by 50%	23.8%
Chenglingji 0	Chenglingji block off, discharge decreases by 100%	0%
Hukou 1.3	The discharge of Hukou increases by 30%	21.1%
Hukou 1.2	The discharge of Hukou increases by 20%	19.7%
Hukou 0.5	The discharge of Hukou decreases by 50%	9.3%
Hukou 0	Hukou block off, discharge decreases by 100%	0%

3.2. Results analysis

3.2.1. *Three outlets.* Corresponding to “current situation”, “three outlet 2.0” will lead to 20% decrease of whole sediment erosion and “three outlet 0” will lead to 20% increase of whole sediment erosion (figure 4). The sediment erosion in reaches from Yichang to Datong have linear correlation with the flow diversion ratio of the three outlets. As if the flow diversion ratio increases by 10%, the sediment erosion of Jing river will decrease by 5.6 million m³. (figure 5)

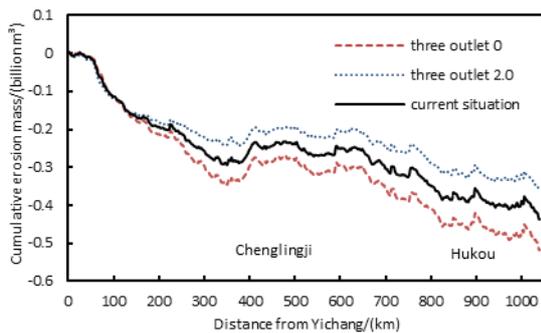


Figure 4. Cumulative erosion volumes distribution under the variation of three outlets discharge

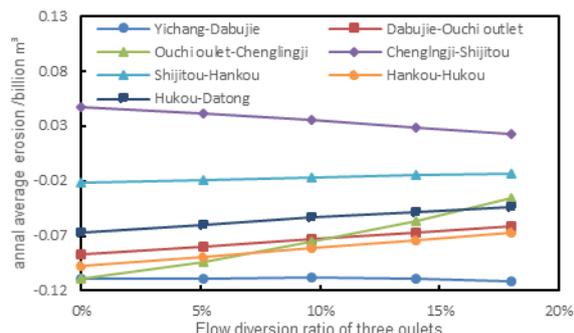


Figure 5. Relationship between annual erosion volumes in each reach and flow diversion ratio of the three outlets

3.2.2. *Chenglingji station.* The sediment erosion above and below Chenglingji are changed with contrary tendency. The upstream of Chenglingji has negative linear correlation with the flow diversion ratio of Chenglingji station. As if the flow diversion ratio increases by 10%, annual sediment erosion of Jing river will decrease by 3.2 million m³. While downstream of Chenglingji station has non-linear correlation with the flow diversion ratio variation of Chenglingji station. (figure 6 & figure 7)

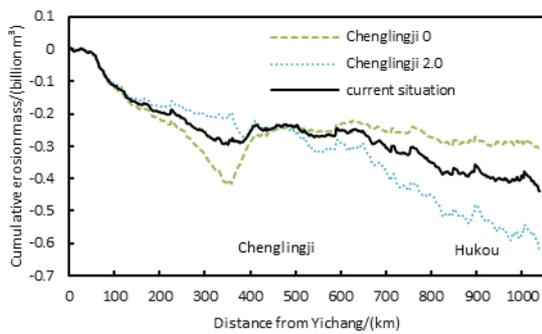


Figure 6. Cumulative erosion volumes distribution under the variation of Chenglingji discharge

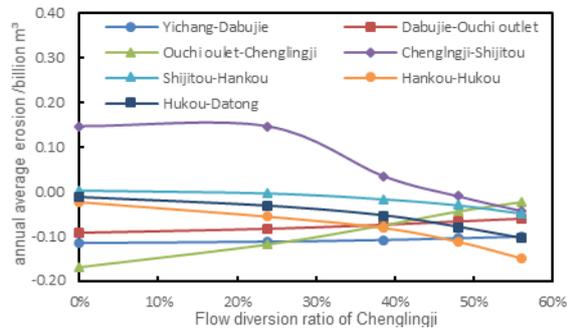


Figure 7. Relationship between annual erosion volumes in each reach and flow diversion ratio of Chenglingji

3.2.3. *Hukou station.* Due to the flow backward of Yangtze River in Hukou, the influence of Hukou diversion is complicated. 10% is the breaking point of flow diversion ratio for the erosion variation: if the value is less than 10%, the correlation between sediment erosion and flow diversion ratio of Hukou station will be positive in Hankou to Hukou reach, but negative in Hukou to Datong reach; but if the flow diversion ratio is more than 10%, the correlation will reverse. (figure 8 & figure 9)

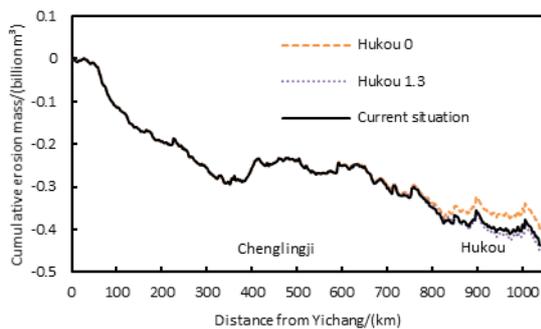


Figure 8. Cumulative erosion volumes distribution under the variation of Hukou discharge

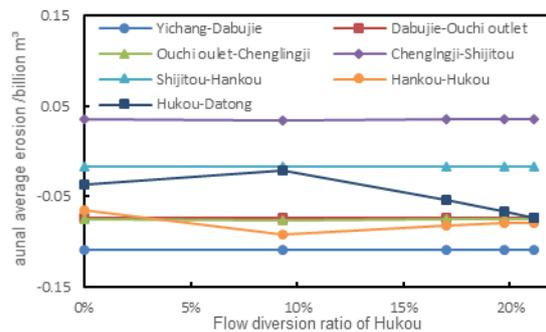


Figure 9. Relationship between annual erosion volumes in each reach and flow diversion ratio of Hukou

4. Conclusions

Based on the observed water-sediment data in 2003-2013, one-dimension river-lake water and sediment numerical model was established and verified. Response regularity of river erosion and deposition distribution to flow diversion ratios was studied through the model. The results show that:

- (1) The sediment erosion in reach from Yichang to Datong has linear correlation with the flow diversion ratio of the three outlets;
- (2) The sediment erosion above Chenglingji has negative linear correlation with the flow diversion ratio variation of Chenglingji station. While the sediment erosion below Chenglingji station has non-linear correlation with the flow diversion ratio variation of Chenglingji station;
- (3) The reach above Hankou station will not be affected by the flow diversion ratio variation of Hukou station. When the flow diversion ratio is less than 10%, the correlation between sediment erosion and flow diversion ratio of Hukou station is positive in Hankou to Hukou reach, but negative in Hukou to Datong reach. However, if the flow diversion ratio is more than 10%, the correlation will reverse.

Acknowledgement

This work was financially supported by the National Key Research and Development Program of China (Grant No. 2016YFC0402307 & No. 2016YFC0402108).

References

- [1] BAN Xuan, JIANG Liuzhi, ZENG Xiaohui, et al. Quantifying the spatio-temporal variation of flow and sediment in the middle Yangtze River after the impoundment of the Three Gorges [J]. *Advances in Water Science*, 2014, 25(05):650-657.
- [2] CAO Wenhong, MAO Jixin. Impacts of Three Georges Reservoir's operation on Jingjiang River and outflow of the three outlets [J]. *Water Resources and Hydropower Engineering*, 2015, 46(06):67-71.
- [3] FANG Chunming, HU Chunhong, CHEN Xujian, et al. Impacts of Three Georges Reservoir's operation on outflow of the three outlets of Jingjiang River and Dongting Lake [J]. *Journal of Hydraulic Engineering*, 2014, 45(01):36-41.
- [4] HU Guangwei, MAO Dehua, LI Zuizheng, et al. Impact on erosion and deposition in main stream by flow and sediment diversion at three outlets along the Jingjiang River [J]. *Journal of Sediment Research*, 2014(03):453-461.
- [5] HU Maoyin, LI Yitian, ZHU Boyuan, et al. Impact on erosion and deposition in main stream by flow and sediment diversion at three outlets along the Jingjiang River [J]. *Journal of Sediment Research*, 2016(04):68-73.
- [6] HUANG Qun, SUN Zhandong, JIANG Jiahu, et al. Impacts of the operation of the Three Gorges Reservoir on the lake water level of Lake Dongting [J]. *Journal of Lake Science*, 2011, 23(03):424-428.
- [7] LI Yitian, GUO Xiaohu, TANG Jinwu, et al. Changes on Runoff Diversion from Jingjiang Reach of the Yangtze River to Dongting Lake after the Operation of Three Gorges Reservoir [J]. *Journal of Basic Science and Engineering*, 2009, 17(01):21-31.
- [8] LU Jinyou, HUANG Yue, GONG Ping, et al. Scouring and silting variation in middle and lower channel of the Yangtze river after TGP [J]. *Yangtze River*, 2006, 37(09):55-57.
- [9] WANG Dong. Research on Change of Yangtze River-Dongting Lake Relations and Flow & Sediment Transport after Operation of Reservoir [D]. Wuhan University, 2014.
- [10] WANG Yangui, LIU Xi, SHI Hongling, et al. Variations and influence factors of runoff and sediment in the Lower and Middle Yangtze River [J]. *Journal of Sediment Research*, 2014(05):38-47.
- [11] WANG Zhili, GENG Yanfen, LU Yongjun, et al. Numerical simulating technology for river flow and sediment and its applications [M]. Beijing: Hohai University Press, 2013: 34-65. (in Chinese)
- [12] XU Jijun, CHEN Jin. Study on the impact of Three Gorges reservoir on Poyang Lake and some proposals[J]. *Journal of Hydraulic Engineering*, 2013, 44(07):757-763.
- [13] XU Jiongxin. Influence of variations in suspended sediment concentration and grain size on sediment deposition of Yichang-Hankou reach of Yangtze River [J]. *Advances in Water Science*, 2006, 17(01):67-73.
- [14] XU Quanxi, ZHU Lingling, YUAN Jin, et al. Research on water-sediment variation and deposition-erosion in middle and lower Yangtze River [J]. *Yangtze River*, 2013(23):16-21. (in Chinese)
- [15] YANG Yunping, ZHANG Mingjin, LI Yitian, et al. Suspended sediment recovery and bed sand compensation mechanism affected by the Three Gorges Project [J]. *Acta Geographica Sinica*, 2016, 71(07):1241-1254.
- [16] ZHU Lingling, CHEN Jianchi, YUAN Jin, et al. Sediment erosion and deposition in two lakes connected with the middle Yangtze River and the impact of Three Gorges Reservoir [J]. *Advances in Water Science*, 2014, 25(03):348-357.
- [17] ZHU Lingling, XU Quanxi, DAI Minglong, et al. Runoff diverted from the Jingjiang reach to the Dongting Lake and the effect of Three Gorges Reservoir [J]. *Advances in Water Science*, 2016, 27(06):822-831.