ICHE 2014, Hamburg - Lehfeldt & Kopmann (eds) - © 2014 Bundesanstalt für Wasserbau ISBN 978-3-939230-32-8

Analysis of Sediment Transport in the Middle Reach of the Yangtze River after Operation of the Three Gorges Project

X. Guo, Y. Zhu, Q. Geng & L. Xinyuan
Key Laboratory of River Regulation and Flood Control of MWR, Yangtze River Scientific Research Institute, Wuhan, China

ABSTRACT: Operation of the Three Gorges Project (TGP) has changed the hydrological regime of the channel downstream. The flow sediment concentration in the middle reach of the Yangtze River will be seriously unsaturated for a long period, and the recovery of the sediment concentration in the flow will cause long distance erosion in the river channel. In this study, with about 60 years of prototype data, the variation of the following aspects of the river after the operation of the TGP are analyzed, the analysis results show that, the annual runoff in the middle reach of the Yangtze River has no obvious trend of change since the operation of the TGP, but the flow sediment concentration reduces significantly; the ratios of flow and sediment diversions via the three outlets only change slightly; it seems that the flow and sediment allocation of the Yangtze River-Dongting Lake system has only relatively small effects on the recovery of flow sediment concentration in the river. The annual sediment transport at all the hydrological stations in the middle reach of the Yangtze River is much less than that before the TGP operation; the part of sediment with d <0.125mm recovers slowly along the river, The main reason (for the insufficient recovery) is that there is little presence of sediment with the right size in the channel of the middle Yangtze River; this is also the fundamental essence of the long distance erosion occurring in the river channel downstream of the TGP. For the part of sediment with d>0.125mm, the recovery speed is relatively fast in the river reach from Yichang to Jianli, and the concentration for this part of sediment recovers almost to the saturation state at Jianli station. The main reason for the fast recovery is that the river channel downstream of the Shashi Station is mainly sandy river bed and there is rich presence of sediment with this size in the bed; this also explains why the erosion occurs mainly in the Jingjiang River so far. Along with the continually construction of cascade reservoirs upstream of the TGP, it is expected according to the current river channel erosion that, if only the part of sediment with d>0.125mm is considered, the averaged annual erosion amount will be generally no more than 3.0×10^7 ton in the middle reach of the Yangtze river in the future.

Keywords: Three Gorges Project, Middle reach of the Yangtze River, Recovery of sediment concentration, Sediment concentration, Long distance erosion, Sediment transport, Hydrological station, Channel downstream of the TGP

1 INTRODUCTION

The middle reach of the Yangtze River, from Yichang to Hukou, is about 954km long, among which, the 347km river reach from Zhicheng to Chenglingji is called the well-known Jingjiang River (see Figure 1). To the south of the Jingjiang River, three outlets (i.e. Songzi, Taiping and Ouchi), divert flow and sediment from the Yangtze River to the Dongting Lake. The Dongting Lake gathers further flow and sediment from its four main tributaries of Xiang River, Zi River, Yuan River and Li River, and then discharges the flow and sediment back into the Yangtze River at Chenglingji. The three Gorges Project (TGP) began to operate in June 2003 with a storage level of 135m, then 156m in Sept. 2006, and 175m in Oct. 2010. After impoundment of the TGP, the reservoir has intercepted the large quantity of sediment; the flow sediment concentration in the channel downstream of the TGP will be seriously unsaturated for a long period, and the recovery of the sediment concentration in the flow will cause long distance erosion in

the river channel. Scour of the river bed will pose a threat to the embankment stability, and impacts on the flood control, water resources utilization, water environment, sustainable economic and social development as well. Therefore, analysis of sediment transport in the middle reach of the Yangtze River after operation of the TGP is very necessary.

Recognition on the sediment transport regularity in the channel downstream of the TGP generally have referred to the reservoirs construction have been completed. The scour distance of river bed is closely related to the flow rate , sediment concentration and riverbed boundary condition (e.g. composition of bed, bed gradient ratio). Qian (1987) and Xie (2002) thinked the long distance erosion in the downstream is due to the sediment carrying capacity gradually decreased, the fundamental reason is the bed sediment tapering,; Han (1987) analyzed the hydraulic conditions and the composition of river bed have effected on scouring and silting of the grouping sediment, it shows that, under the hydraulic conditions changing little, the coarse particle proportion decreasing and the fine particles proportion increasing in river bed is the main cause of the coarse particle deposition and fine particle erosion; Ii(2003) pointed out that, sediment transportation capacity of each grain group size after the reservoir operation can't exceed its original level before the reservoir's operation; Chen(2010) thinked, the main reason of the long distance scour in the downstream is bed sediment supply poor, especially the fine sand supplies shortage. Although these results explained the general rules of sediment transportation in the channel downstream of the reservoir, the results of sediment transportation in the channel downstream of TGP is less. Base on the measured data of Three Gorges Project application, the sediment transport in the middle reach of the Yangtze River has systematically analyzed, the results can provide technical support for river regulation, planning , relationship between river and lake in the middle reaches of the Yangtze River.

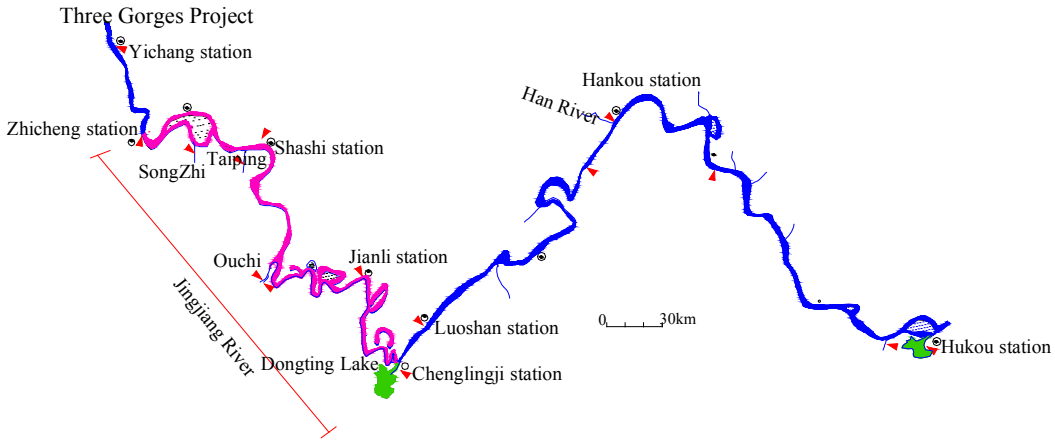


Figure 1. Sketch map of the middle Yangtze River.

2 ANALYSIS ON VARIATION OF WATER AND SEDIMENT LOAD IN THE MIDDLE REACH OF THE YANGTZE

Zhicheng is an important hydrological station in the Jingjiang River (see Figure 1). The variation of the runoff and sediment concentration at Zhicheng Station is analyzed (see Figure 2).

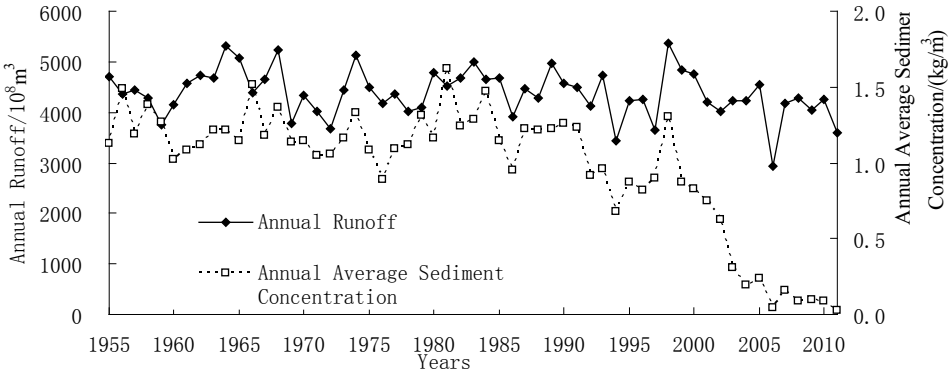


Figure 2. Variation of annual runoff and annual averaged sediment concentration at Zhicheng station (1955-2011).

Figure 2 shows, the annual runoff is of no notable variation tendency during the last 60 years, but comparing with that before the TGP operation, the annual runoff is about 9.4% less after the operation of the

TGP. The main reason is that there is not appear flood year and appear dry years in 2006,2011 after operation of the TGP. The average sediment concentration is also of no notable variation tendency at Zhicheng station before 1990. The average sediment concentration is 1.21kg/m^3 during 1955-1989, after that it is in a decreasing tendency and the average number reduced to 0.925kg/m^{3}during 1990-2002. comparing with that during 1955-1989, the number is about 23.3% less during 1990-2002; After impoundment of the TGP, the giant reservoir has intercepted the large quantity of sediment, and the average sediment concentration reduces drastically during 2003-2011 to 0.139kg/m^{3,} which is about 84.9% less comparing with that during 1955-1989.

Variations of the flow and sediment diversion via the three outlets (i.e. Songzi, Taiping and Ouchi) from the Jingjiang River to the Dongting Lake are summarized in Fig 3, the ratios of flow and sediment diversion is referred to the runoff and sediment discharge at Zhicheng Station. Under natural conditions the ratios of flow and sediment diversion decreases gradually before 1990. Since the operation of the TGP, except in 2006, 2011 in which the ratios had a significant reduction, the ratios have no clear trend of unidirectional change for the other years in 2003~2011. It seems that the flow and sediment allocation of the Yangtze River- Dongting Lake system has only relatively small effects on the recovery of flow sediment concentration in the river.

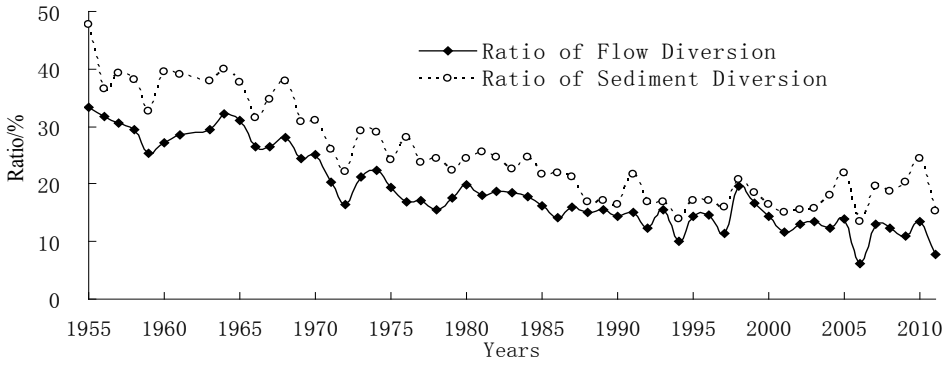


Figure 3. Variations of the flow and sediment diversion via the three outlets from the Jingjiang River (1955-2011).

3 ANALYSIS OF SEDIMENT TRANSPORT IN THE MIDDLE REACH OF THE YANGTZE RIVER

Operation of the TGP has changed the hydrological regime of the channel downstream, leading to change of the sediment transport. The different grain size distribution of bed material in the middle reach of the Yangtze River causes different recovery degree and recovery distance, variation of of grain size distribution of bed material in the middle reach of the Yangtze River are analyzed (see Figure4).

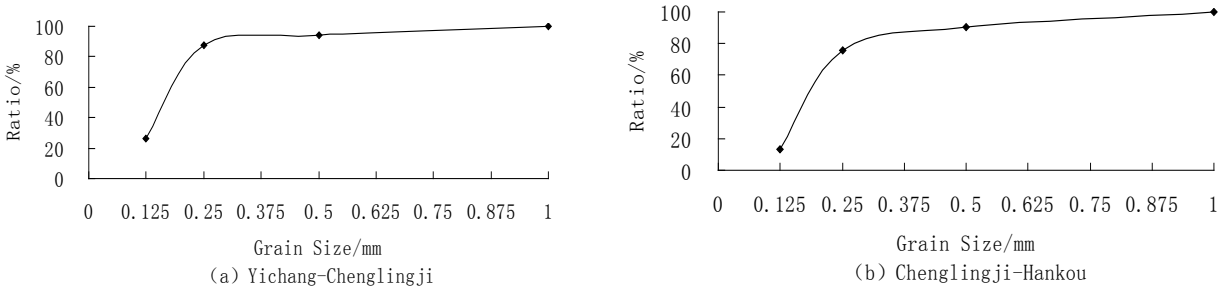


Figure 4. Variation of grain size distribution of bed material along Yichang~Hankou reach.

Figure 4 shows that the part of sediment with $d > 0.125$mm is rich present and $d < 0.125$mm is relatively little present in the Yichang -Chenglingji bed; this grain size distribution is also same in Chenglingji - Hankou bed.

The average annual sediment discharge in the middle reach of the Yangtze River are counted for the period before and after the TGP operation, respectively (see Figure5). The ratios of flow and sediment diversion are of no notable variation tendency after 1992.

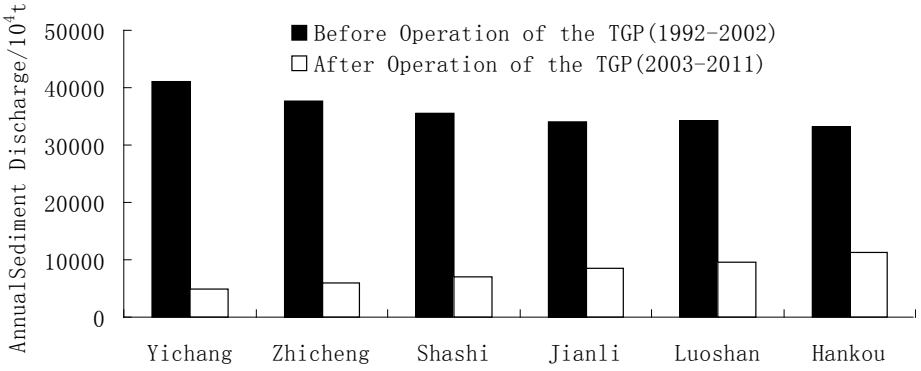
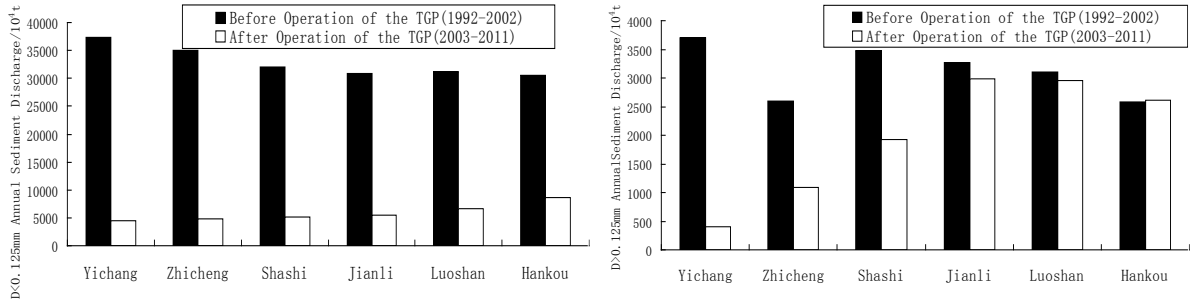


Figure 5. Average annual sediment discharge at hydrological stations in the middle Yangtze River before and after operation of the TGP.

Comparing with that before the TGP operation, the annual sediment discharge in the middle reach of the Yangtze River reduces greatly after the TGP operation, and the sediment discharge is in an increasing tendency along the river.

The changes of the part of sediment with d < 0.125mm and d > 0.125mm at the main hydrological stations in the middle reach of the Yangtze River are counted for the period before and after the TGP operation, respectively (see Figure 6).



(a) *d* <0.125mm (b) *d*>0.125mm

Figure 6. Comparison of the different fractions of suspended load in the middle reach of the Yangtze before and after operation of the TGP.

Comparing with that before the TGP operation, the part of sediment with d < 0.125mm reduces greatly after the TGP operation. The part of sediment with d < 0.125mm is relatively little present in the middle reach of the Yangtze River, so this part of sediment recovers slowly along the river, and the degree of recovery is far less than that before the operation. It seems that the main reason for the long distance erosion in the downstream channel is the poor supply of the sediment with d <0.125mm.

The part of sediment with d >0.125mm also reduces greatly after the TGP operation. The part of sediment with d >0.125mm is relatively rich present in the middle reach of the Yangtze River. The rate of recovery is relatively fast in the river reach from Yichang to Jianli for the part of sediment with d>0.125mm, and the sediment concentration recovers almost to the saturation state at the Jianli, Luoshan, and Hankou stations.

The sediment proportions d >0.125mm and d <0.125mm at the main hydrological stations in the middle reach of the Yangtze River are counted respectively for the period after the TGP operation (see Figure7).

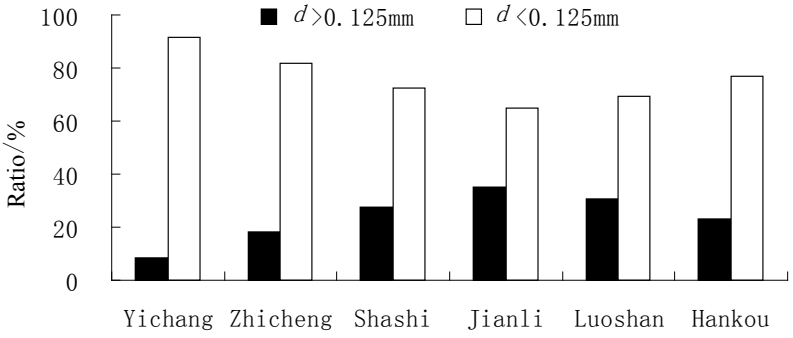


Figure 7. Sediment proportions of the two grain sizes in the middle Yangtze River after operation of the TGP.

It can be seen from the figure that, the sediment proportion for the part of sediment with d >0.125mm is much less than that part with d <0.125mm, especially at Yichang station, at which the part of sediment with d >0.125mm has the smallest proportion. Yet, the part of sediment with this size is rich present in the channel of the middle reach of the Yangtze River, thereforethe recovery speed is relatively fast in the river reach from Yichang to Jianli, and consequently the sediment proportion for this size increases significantly. Affected by the converge confluence of the Dongting Lake and the Han River, the sediment proportion with d >0.125mm declines to a certain degree at the Luoshan and Hankou stations.

4 DISCUSSION OF SEDIMENT TRANSPORT AFTER OPERATION OF THE THREE GORGES PROJECT

Operation of the TGP has changed the hydrological regime of the channel downstream. The flow sediment concentration in the middle reach of the Yangtze River will be seriously unsaturated for a long period, and the recovery of the sediment concentration in the flow will cause long distance erosion in the river channel. The river channel downstream of the Shashi Station is mainly sandy river bed and easy to suffer from flow erosion. Since the operation of the TGP, the flow and sediment diversion via the three outlets from the Jingjiang River to the Dongting Lake have no clear trend of unidirectional change in 2003-2011. According to the research results so far, the flow and sediment diversion via the three outlets will maintain the original pattern in a certain long time in the future. in the next period of time.
The part of sediment with d >0.125mm is rich present in the middle reach of the Yangtze, therefore the suspended load recovery rate is relatively fast in the river reach from Yichang to Jianli, and the concentration for this part of sediment recovers almost to the saturation state at Jianli station. This also explains why the erosion occurs mainly in the Jingjiang River so far. The part of sediment with d <0.125mm is relatively little present in the middle reach of the Yangtze, therefore the part of sediment with this size recovers slowly along the river, and the degree of recovery is far less than that before the operation. This is also the fundamental essence of the long distance erosion occurring in the river channel downstream of the TGP.

The cascade giant reservoirs, such as the Xiangjiaba, the Xiluodu, the Baihetan, and the Wudongde, is under construction or planned to be constructed in the upper reach of the Yangtze. After their operation the flow sediment concentration in the middle reach of the Yangtze River will be further unsaturated for a longer period, and the recovery of the sediment concentration in the flow will cause longer distance erosion in the river channel. River bed longitudinal slope will become flat as time goes on, and the main erosion also will gradually move down. The part of sediment with d >0.125mm is rich present in the middle reach of the Yangtze, and the concentration for this part of sediment is expected to be able to recover almost to the saturation state. Along with the continually construction of the cascade reservoirs upstream of the TGP, it is expected according to the current river channel erosion as observed at Jianli, Luoshan, and Hankou stations, if only the part of sediment with d>0.125mm is considered, the averaged annual erosion amount will be generally no more than 3.0×107 ton in the middle reach of the Yangtze river in the future.

5 CONCLUSIONS

The annual runoff is of no notable variation tendency during the last 60 years in the Jingjiang River. The average sediment concentration is of no notable variation tendency before 1990, however, decreased during 1990-2002; after the operation of the TGP, the average sediment concentration reduces drastically during 2003-2011.

The flow and sediment diversion via the three outlets from the Jingjiang River decreases gradually before 1990; after the operation of the TGP, the ratios of flow and sediment diversion have no clear trend of unidirectional change in 2003-2011.

The part of sediment with d <0.125mm is relatively little presence in the middle reach of the Yangtze River, therefore this part of sediment recovers slowly along the river, and the degree of recovery is far less than that before the operation. The part of sediment with d >0.125mm is relatively rich presence in the middle reach of the Yangtze River. For this part of sediment, the recovery speed is relatively fast in the river reach from Yichang to Jianli, and the concentration for this part of sediment recovers almost to the saturation state at Jianli station.

Along with the continually construction of cascade reservoirs upstream of the TGP, if only the part of sediment with d>0.125mm is considered, the averaged annual erosion amount will be generally no more than 3.0×10^7 ton in the middle reach of the Yangtze river in the future.

ACKNOWLEDGEMENT

This study was financially supported by the Public Welfare Scientific Research Funding Project of the MWR of China (Grant No. 201401011), the National Natural Science Foundation of China (Grant No. 51339001), and the National Key Technology R&D Program of China (Grant No. 2012BAB04B03).

REFERENCES

Qian, N, and Zhang,R.(1987) The riverbed evolution , Science Press, Beijing, China, 575 pages.
Xie, J.H.(2002),The riverbed evolution and renovation , Water conservancy and Hydropower Press, Beijing, China, 213 pages.
Han, Q.W.(2003),Reservoir sedimentation , Science Press, Beijing, China, 643 pages.
Li, Y.T.,Sun, Z.H. et al. (2003) A Study on Riverbed Erosion Downstream from the Three Gorges Reservoir, Journal pf Basic Science and engineering, Vol. 11 ,No. 3,pp.283-295.
Che, F, Li, Y.T et al.(2010) Analysis of group sized sediment transport downstream a reservoir, Vol.29 No. 1, pp. 164-170.