Conference Paper, Published Version

Yonghui, Zhu; Xiaohu, Guo; Hongzhi, Liao; Guangshi, He; Geng, Qu

Impacts of the Three Gorges Project on the Hydrological Regime in the Jingjiang Reach of the Yangtze River

IMPACTS OF THE THREE GORGES PROJECT ON THE HYDROLOGICAL REGIME IN THE JINGJIANG REACH OF THE YANGTZE RIVER

Zhu, Yonghui[1], Guo Xiaohu[2], Liao Hongzhi[3], He Guangshi[4], and Qu Geng[5]

ABSTRACT

The Jingjiang Reach, part of the middle reach of the Yangtze River, is very closely downstream of the Three Gorges Project (TGP). Based on measured prototype hydrological data from 1950 to 2010, impacts of the TGP on the hydrological regime of the Jingjiang Reach are analyzed. The results showing that the runoff of the river is of no clear variation tendency during the last 60 years. However, after the operation of the TGP, the sediment concentration of the flow in the Jingjiang Reach decreased by 75%; coarsening of the suspended load and bed load in the river is evident; the water level at the same flow rate has a tendency to decline, with the margin of decline at smaller flow rate being larger than that at larger flow rate. The flow and sediment diversion from the Yangtze River to the Dongting Lake via the three outlets also has a tendency to decrease; the degree of decrease of the sediment diversion is much larger than that of the flow diversion.

1. INTRODUCTION

The Jingjiang Reach, from Zhicheng to Lianhuatang, is about 347.2 km long, part of the middle reach of the Yangtze River, and typical of alluvial meandering river (Figure 1). Bounded by Ouchikou, the Jingjiang Reach is divided into the Upper Jingjiang Reach and the Lower Jingjiang Reach. The Jingjiang Reach is the most flooding vulnerable section in the Yangtze River. Three outlets, i.e. Songzikou, Taipingkou and Ouchikou, mainly formed due to historical big floods, 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 Lianhuatang. The relationship between the Yangtze River and the Dongting Lake

[1] Senior Engineer, River Department, Changjiang River Scientific Research Institute, 23 Huangpu Street, 430010, Wuhan, China (yhzhu75@yahoo.com)
[2] Engineer, River Department, Changjiang River Scientific Research Institute, 23 Huangpu Street, 430010, Wuhan, China (xiaohu001328@163.com)
[3] Senior Engineer, Headquarter of Changjiang Flood Control and Drought Relief, 1863 Jiefang Dadao, 430010, Wuhan, China (liaohongzhi75@yahoo.com.cn)
[4] Senior Engineer, River Department, Changjiang River Scientific Research Institute, 23 Huangpu Street, 430010, Wuhan, China (hgswh@126.com)
[5] Engineer, River Department, Changjiang River Scientific Research Institute, 23 Huangpu Street, 430010, Wuhan, China (qugeng0516@163.com)

is the well-known so-called complicated River-Lake Relationship in China (Yu and Lu, 2005).

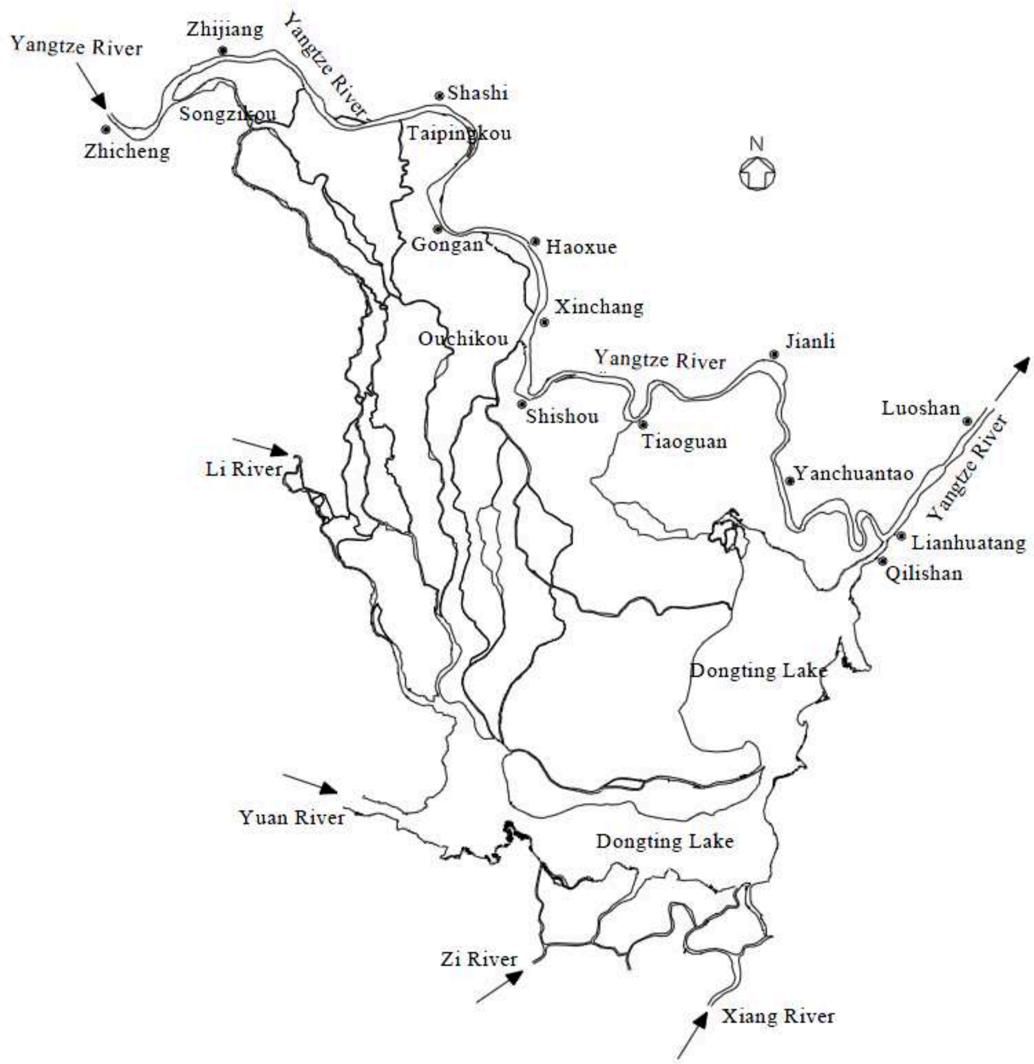

Figure 1 Schematized illustration of the Jingjiang Reach and the Dongting Lake.

The Three Gorges Project (TGP), as one of the largest hydropower-complex project in the world, ranks as the key project for improvement and development of the Yangtze River. With a normal storage level of 175m, the total capacity of the reservoir reaches 39.3 billion m^3, of which the effective flood control capacity reaches 22.15 billion m^3. In June 2003 the storage level of the reservoir reached 135m, then 156m in September 2006, and 175m in October 2010, indicting the realization of the integrated targets of the Project in terms of flood protection, electricity generation, and navigation, etc. The operation of the TGP has changed the flow and sediment conditions (i.e. the hydrological regime) of the river channel downstream, among others, the Jingjiang Reach, closely downstream of the dam, is affected relatively earlier and significant. Based on prototype hydrological data from 1950 to 2010, variations of the hydrological regime in the Jingjiang Reach after operation of the TGP are analyzed.

2. VARIATIONS OF HYDROLOGICAL REGIME

2.1 Variations of Runoff and Sediment Load

The runoff and sediment of the Jingjiang Reach comes mainly from the upstream Yangtze main stem. Operation of the TGP reduces the peak of big floods and increases the flow rate for dry season. Generally, the flow process is flattening within the year. The annual runoff is about 5%~10% less after the operation of the TGP, except the Jianli Station, which increased slightly mainly due to decrease of flow diversion via the three outlets from the Jingjiang Reach to the Dongting Lake (Table 1). Yet, generally the runoff of the river is of no notable variation tendency during the last 60 years (CRSRI, 2012).

Operation of the TGP has very clear impacts on the sediment load of the Jingjiang Reach (Tables 1 and 2). The stations of Zhicheng, Shashi and Jianli are, respectively, the control stations of the entrance of the Jingjiang Reach, of the Upper Jingjiang Reach and the Lower Jingjiang Reach. Comparing with that before the TGP operation, the sediment load decreased by 87.1%, 82.4% and 75.0% for stations of Zhicheng, Shashi and Jianli, respectively. Table 2 indicates that the sediment concentration of the flow decreased significantly after the operation of the TGP, and the further upstream the station is, the larger the decrease will be. Due to the erosion along the channel, the sediment concentration recovers consequently.

Table 1 Variations of runoff and sediment load

Station	Averaged annual runoff （10^8m^3）	Averaged annual sediment load （10^8t）	Period	Averaged annual runoff （10^8m^3）	Averaged annual sediment load （10^8t）	Period
Zhicheng	4455	5.10	1955-2002	4071	0.658	2003-2010
Shashi	3934	4.34	1956-2002	3751	0.766	2003-2010
Jianli	3536	3.58	1951-2002	3616	0.895	2003-2010
Songzikou	419	0.464	1955-2002	293	0.065	2003-2010
Taipingkou	165	0.185	1954-2002	95	0.018	2003-2010
Ouchikou	381	0.584	1956-2002	112	0.041	2003-2010

Table 2 Variations of sediment concentration, kg/m^3

	Zhicheng	Shashi	Jianli
Normal value of accumulated year before operation of TGP	1.124	1.101	1.001
Average value after operation of TGP	0.16	0.20	0.25

Note: period before operation of TGP: Zhicheng 1955~2002, Shashi 1956~2002, Jianli 1951~2002; period after operation of TGP: 2003~2010

2.2 Variations of Water Level

To analyze the variations of water level in the Jingjiang Reach at the same flow rate before and after operation of the TGP, prototype measurements have been analyzed for stations of Zhicheng, Shashi and Xinchang, as shown in Table 3 (CRSRI, 2012).

The decline of water level at flow rate of 5000m^3/s is relatively small for the Zhicheng Station (Table 3), yet at 10000m^3/s the decline reaches 0.6m. For the Shashi Station, the decline of water level is relatively large at flow rate below 10000m^3/s, among others, 0.81m for 5000m^3/s. The Xinchang Station has the same tendency of water level decline as the Shashi Station, only with a slightly smaller margin. In general, the water level at the same flow rate has a tendency to decline after TGP operation, with the margin of decline of the Upper Jingjiang Reach being larger than that of the lower Reach, and that at smaller flow rate being larger than that at larger flow rate.

Table 3 Variations of water level at the same flow rate after operation of the TGP (m).

Stations	Period / Flow rate (m^3/s)	2002~2003	2003~2005	2005~2007	2007~2010	2002~2010
Zhicheng	5000	-0.01	-0.03	-0.14	-0.03	-0.21
	10000	-0.03	-0.15	-0.2	-0.22	-0.6
	20000	-0.04	-0.04	-0.04	-0.06	-0.18
	30000	-0.02	0.16	0.04	-0.01	0.17
	40000	0	0.08	0.04	0.07	0.19
Shashi	5000	-0.25	-0.3	-0.15	-0.11	-0.81
	10000	-0.12	-0.1	-0.12	-0.23	-0.57
	20000	-0.03	-0.08	0.14	-0.06	-0.03
	30000	-0.01	-0.04	0.05	0.05	0.05
Xinchang	5000	-0.21	-0.26	-0.1	-0.04*	-0.61**
	10000	-0.1	-0.1	-0.1	-0.12*	-0.42**
	20000	-0.04	-0.06	0.04	-0.1*	-0.16**
	30000	-0.03	-0.03	0.04	-0.03*	-0.05**

* Period 2007~2008; ** Period 2002~2008

2.3 Variations of Suspended and Bed Load

The middle and lower Yangtze is typical of alluvial river with frequent and strong exchange between the suspended load and bed load. The particle diameter of suspended load is not only related to the upstream incoming sediment and the boundary conditions of the river channel, but also closely to the features of erosion and deposition. Variations of suspended load at main hydrologic stations after operation of the TGP are summarized in Table 4. On the one hand, after operation of the TGP most of the coarse sediment particles are stopped in the reservoir, resulting in fine down of the suspended load discharged from the reservoir. On the other hand, the clear flow discharged from the reservoir causes significant erosion along the river channel. Downstream of the TGP, the suspended load is coarsened distinctly, especially that at the Jianli Station, where d_{50} coarsened from 0.009mm before operation to 0.15mm of 2006, to 0.056mm of 2007, 0.109mm of 2008, and then to 0.105mm of 2010. The content of sediment coarser than 0.125mm in the suspended load from Yichang to Jianli is increased significantly, from 2.6% to 41.4% in 2007, and from 2.1% to 46.8% in

2008. Downstream of the Jianli Station, the suspended load tends to be finer along the river, i.e. the content of sediment coarser than 0.125mm decreased along the river.

Table 5 indicates that from 2003 to 2007, at Yichang Station, the medium diameters of the bed load are 0.320 mm, 0.402 mm, 0.480 mm, 0.680mm and11.7mm, respectively, showing a clear coarsen trend. For the Zhicheng Station, the medium diameters of the bed load are 0.280mm, 0.271mm, 0.30mm, 0.296mm and 0.307mm for 2003, 2005, 2006, 2007 and 2008, though fluctuates slightly, still showing a general coarsen trend. The content of sediment finer than 0.25mm in the bed load at Zhicheng Station decreases significantly, from 42.5% in 2003 to 26.9% in 2009. The bed load at Jianli Station also shows a certain coarsen trend with the medium diameter being 0.154mm, 0.171mm, 0.195mm, 0.239mm, 0.198mm, 0.176mm and 0.184mm for 2003~2009, respectively. The d_{50} of the bed load at Luoshan Station has no clear variation.

Table 4 Variations of suspended load at main hydrologic stations after operation of TGP.

	Period or year	Weight percentage (%)				
		Yichang	Zhicheng	Shashi	Jianli	Luoshan
d>0.125 (mm)	before operation TGP*	9	6.9	9.8	9.6	13.5
	2003	14	25.8	26.6	19.4	21
	2004	8.9	22.5	31.7	39.7	28
	2005	5.4	12.6	23.9	28.4	22.9
	2006	2.2	16.8	45.7	57	36.2
	2007	2.6	19	32.2	41.4	29.1
	2008	2.1	15.1	33.8	46.8	32
	2009	2.5	17.5	36.5		
	2010		6.2	18.5	26.5	
medium diameter (mm)	before operation TGP*	0.009	0.009	0.012	0.009	0.012
	2003	0.007	0.011	0.018	0.021	0.014
	2004	0.005	0.009	0.022	0.061	0.023
	2005	0.005	0.007	0.013	0.025	0.01
	2006	0.003	0.006	0.099	0.15	0.026
	2007	0.003	0.009	0.017	0.056	0.018
	2008	0.004	0.006	0.017	0.109	0.014
	2009	0.003	0.006	0.011		
	2010		0.007	0.01	0.015	

* Stations Yichang and Jianli: 1986~2002; Zhicheng Station: 1992~2002; Shashi Station: 1991~2002; Luoshan Station: 1987~200

Table 5 Variations of bed load at main hydrologic stations after operation of TGP.

	Period or year	Weight percentage (%)				
		Yichang	Zhicheng	Shashi	Jianli	Luoshan
d<0.25 (mm)	Oct. 2003	26.6	42.5	63.8	94.6	90.6
	Oct. 2004	17.8			93.8	86.5
	Oct. 2005	3.8	40.6	67.4	85.9	85
	Oct. 2006	1.8	0.2	53.5	53.5	86.8
	Oct. 2007	2.4	28.4	49.7	84.8	87.34
	Oct. 2008		12.3	1.1	89.2	
	Oct. 2009		26.9	48	86.1	
medium diameter (mm)	Oct. 2003	0.32	0.280	0.215	0.154	0.19
	Oct. 2004	0.402			0.171	0.18
	Oct. 2005	0.48	0.271	0.212	0.195	0.18
	Oct. 2006	0.68	0.300	0.239	0.239	0.19
	Oct. 2007	11.7	0.296	0.251	0.198	0.21
	Oct. 2008		0.307	0.252	0.176	
	Oct. 2009		0.301	0.253	0.184	

2.4 Variations of Flow and Sediment Diversion from the Three Outlets

Variations of the flow and sediment diversion via the three outlets from the Jingjiang Reach are summarized in Figures 2~4. Under natural conditions the ratios of flow and sediment diversion decreases gradually. Since the operation of the TGP, except 2006 which is a special low flow year, in which the ratios of flow and sediment diversion has a significant reduction, the ratios are of no clear unidirectional variation tendency in the other years in 2003~2010.

Prototype data in the last nearly 50 years indicate that, due to the constantly reduction of the flow diversion via the three outlets from the Jingjiang Reach before 1990s, the flow rate at the three outlets in median and low water period decreases continuously and the numbers of days of flow stoppage increases (Figure 5).

After the operation of the TGP, the numbers of days of flow stoppage shows no clear variation trend. Take the Guanjiapu Station of Ouchikou as an example, before the systematic river cutoff of the Lower Jingjiang Reach in 1967~1972, the number of days of flow stoppage of the Guanjiapu Station varies randomly. The systematic river cutoff induced drastically fall of the nearby water level of the Yangtze River, which caused straight climb of the number (as can be seen from Figure 5); from 1973~2002, due to the further fall of the water level of the Yangtze River close to the three outlets, and due to the siltation of the outlets themselves, the number of days of flow stoppage increases further; yet the number is of no clear variation trend so far since 2002.

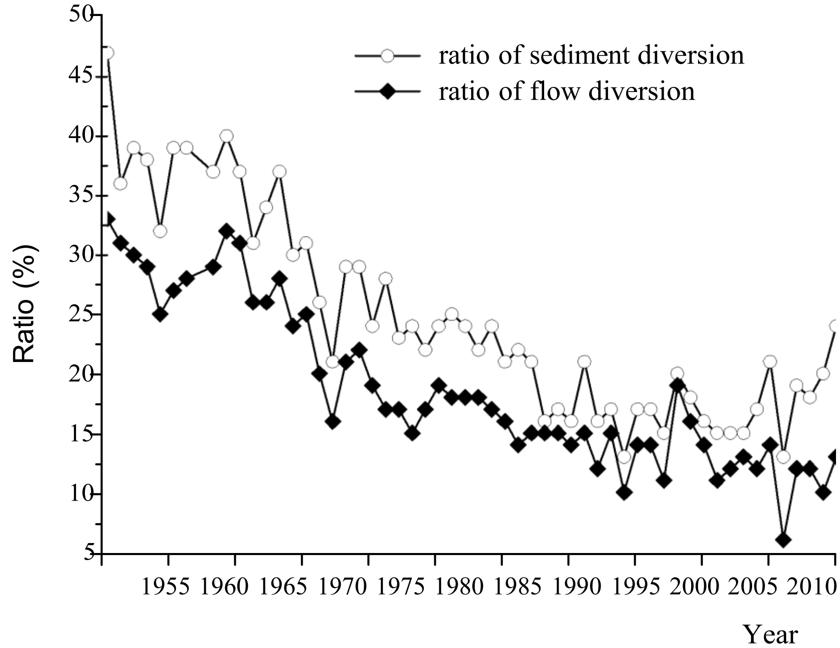

Figure 2 Variations of the ratios of flow and sediment diversion via the three outlets.

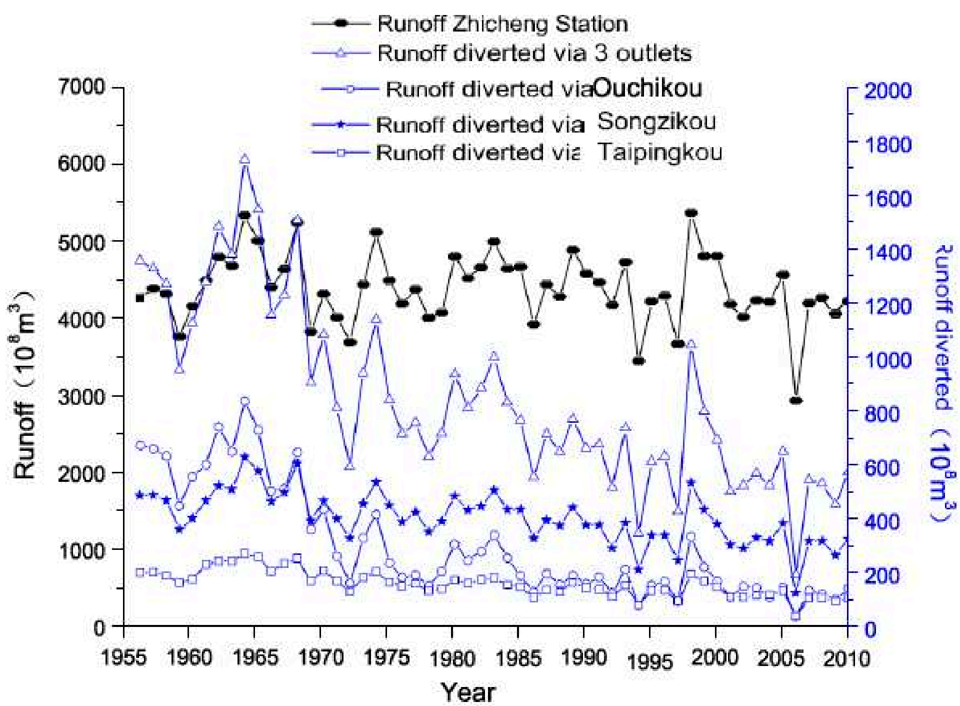

Figure 3 Variations of runoff diversion via the three outlets from the Jingjiang Reach.

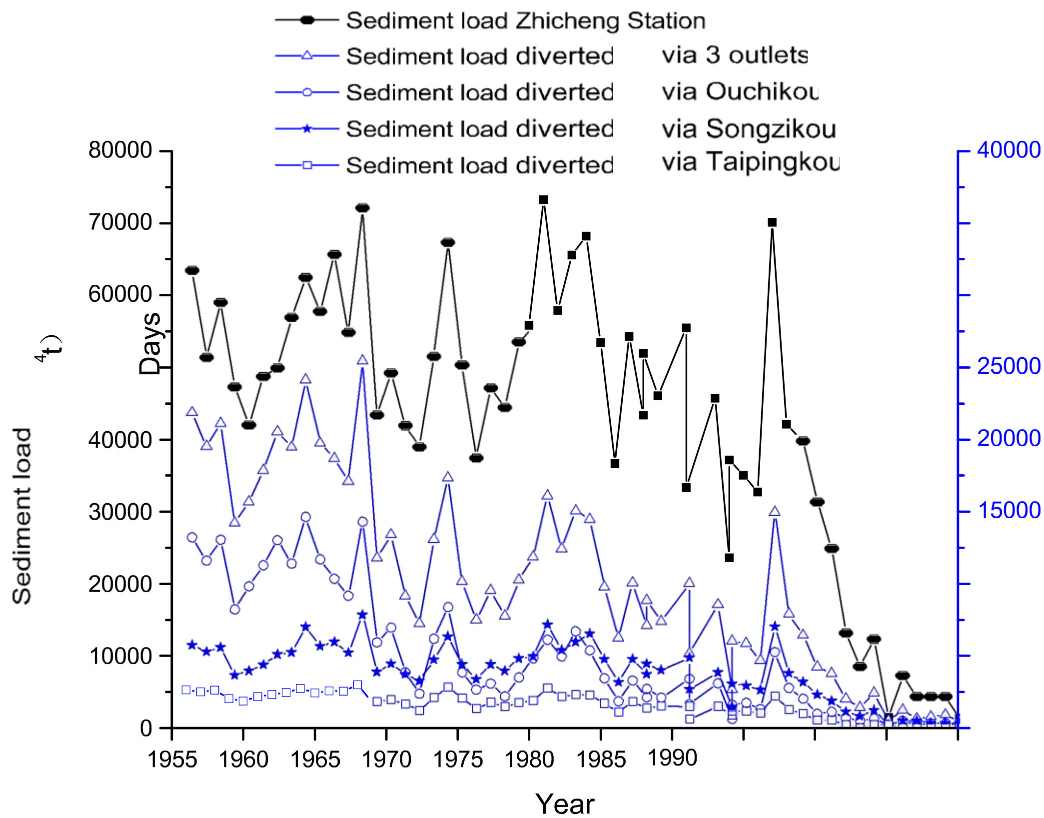

Figure 4 Variations of sediment load diversion via the three outlets from the Jingjiang Reach.

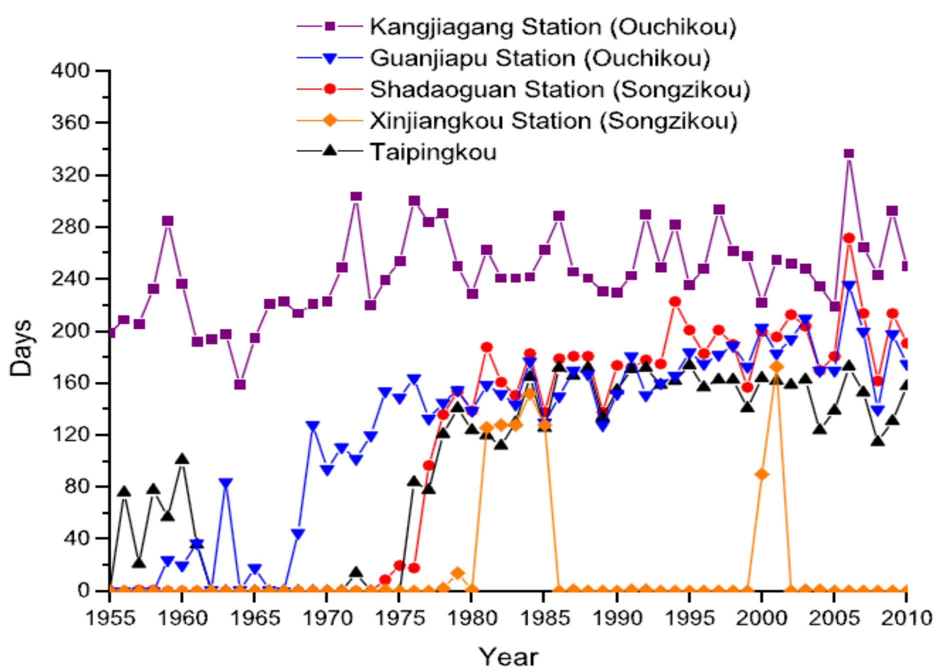

Figure 5 Number of days of flow stoppage at the 5 hydrological stations of the three outlets.

3. CONCLUSIONS

The operation of the TGP changed the flow and sediment conditions (i.e. the hydrological regime) of the river channel downstream. Based on the measured prototype hydrological data from 1950 to 2010, variations of the hydrological regime in the Jingjiang Reach after operation of the TGP are analyzed. The results showing that the runoff of the river is of no clear variation tendency during the last 60 years. Yet, after the operation of the TGP, the sediment load decreased at least by 75%; coarsening of the suspended and bed load is evident; the water level at the same flow rate has a tendency to decline, with the margin of decline of the Upper Jingjiang Reach being larger than that of the Lower Reach, and that at smaller flow rate being larger than that at larger flow rate. The flow and sediment diversion from the Yangtze River to the Dongting Lake via the three outlets has a tendency to decrease; the degree of decrease of the sediment diversion is much larger than that of the flow diversion. Except 2006 which is a special low flow year, in which the decrease of the ratios of flow and sediment diversion are relatively large, the ratios are of no clear unidirectional variation tendency in the other years after operation of the TGP.

ACKNOWLEDGEMENTS

This work was supported by the Water Conservancy Pilot Study Project of China "Evolution and training of the Jingjiang River in the early operation phase of the Three Gorges Project"

REFERENCES

CRSRI (2012). Evolution and Training of the Jingjiang Reach in the Early Operation Phase of the Three Gorges Project, The Changjiang River Scientific Research Institute, Wuhan, China. (in Chinese)

YU Wenchou, LU Jinyou (2005). Evolution and Regulation of the River Channel of the Yangtze River, China Water Power Press, Beijing. (in Chinese)