Study on Sediment Problems at the Fluctuating Backwater Area of Three Gorges Reservoir

JIN Zhong-wu[1], GUO wei[2], Fan beilin[3]

Changjiang River Scientific Research Insititute,Wuhan 430010,China,

1,E-mail:zhongwujin@163.com

2, E-mail:zhongwujin@163.com

3, E-mail:fbl0907@yahoo.com

Abstract: Based on the analysis of the reservoir inflowing runoff and sediment feature and the silting and scouring law at the fluctuating backwater area during its pre & post operation period of Three Gorges project(TGP), it can be concluded that: Silting and scouring are basically equilibrated year-to-year before the building of the reservoir in the reach and inflowing sediment load decreased greatly within 5-year operation of TGP after the building of the reservoir; it is generally silted in the reach, primarily on the marginal bank, while it has little siltation even some scouring in the trough; River regime of Tunaozi reach has been changed; As a result of the silt trapping of up-stream reservoir, the speed of the sediment siltation will be little than prediction.

Key words: reservoir area of Three Gorges project(TGP); fluctuating backwater area; silting and scouring law

1 Introduction

Three fluctuating backwater areas will form during impounding period of 135m (139m), 156m, 175m Water Level when the Three Gorges Project is being built and the process is completed, and the entire fluctuating backwater area scope is between Yangjiao Beach of Jiangjin and Fengdu in Chongqing City. Fluctuating backwater areas will appear the reservoir state and the natural watercourse alternatively, and the characteristics of silting and scouring will also change greatly. We have already got some research results on these problems such as the changes of silting and scouring law, the river regime transformation, navigation and so on in the process of the argumentation and designation of the Three Gorges Project(TGP) [1]-[5]. At present, Three Gorges reservoir has already operated for 5 years and experienced the impounding period of 135m (139m), 156m Water Level. The river reach between Fengdu and Lidu is at the fluctuating backwater area during the impounding period of 135m, 156m Water Level and would be in perennial backwater area during the impounding period of 175m Water Level. Therefore, we choose the river reach between Fengdu and Lidu to analyze and study its sediment silting and scouring law during the pre & post operation period of TGP,which has the inspection and reference value for studying the watercourse silting and scouring law of fluctuating backwater area of TGP and features of river bed evaluation of this reach.

2 General situation of watercourse

The river reach between Fengdu and Lidu is 80.9km long and the river bed is 850.00m wide in average, which is up to Lidu town in Fouling and down to Xingyi town in Fengdu. See figure 1. It contains 2 successive curves which are in the river reach between Lidu and Huangqi and between Huangqi and

Guojiazui respectively, a regular reach in Qingxichang and a curve in Siguazi from up to down. The river reach of the 2 curves in up-stream is alternated with wide and narrow reach and the mean water river width is about 500m to 900m. The current of the down reach in Fuling city is quite complex for the irregularity coastline, blocks and rock overhangs extending to river usually, wavy river bed, where slack flow and deep gulf and swift or cascade are existed alternatively and jacking function conduced by confluence of two rivers. The river reach of Qingxichang canyon is about 5km long and the water surface is 300m to 500m wide, the cross section of which is V in shape, bank slope is steep and current is turbulent and swift. The river reach of Pingsui dam is branched off by the moraine dam to left branch which is the main course and right branch which has water interception in dry season and the river width is up to 2300m wide in flood season. The Siguaqi curve contains the Siguaqi reaches of up, mid and down, which is the moraine dam locating in the concave bank of the curve. The curve is about 6.5km long and 150m to 500m wide. Both sides of the regular reach in Fengdu are low-relief and hills terrain, the surface relief of which is gentleness. The reach which is about 1.2km wide is regular and slightly curved in plane and is rather wavy in longitudinal section. The up reach is narrow and deep while the down is wide and shallow. The narrowest reach is about 530m and get wide down while the widest is about 1750m. rock girders such as Canbei girder, Ma dam, Fengwei dam etc. lie in the river in this river reach.

The river reach between Fengdu and Lidu which locates in the southeast border transition zone of Sichuan basin belong to low and deep hills and valley form. It bestrides the north of Changjiang River to the south of that and passes through the east of Wujiang river to the west of that. It is high in the southeast of this river reach and low in the northwest of that. The cross section from northwest to southeast of this reach shows a symmetrical saddle shape which leans against Changjiang River valley. The variety of morphology types in this region is of hills and bench terrace in main and low, media hills and flat dam in subordination. The integral morphology pattern shows that narrow low hill anticline alternates with wide and slow syncline in order.

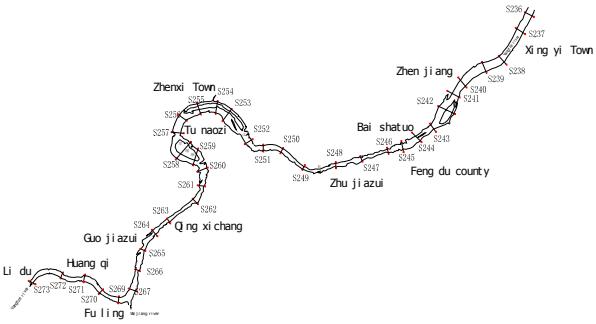

Fig.1 The river regime from Fengdou to Lidu

3 River bed evolution before utilization of Three Gorges Project

The sediment silting and scouring is closely related to inflowing runoff and sediment, river bed morphology and local terrain in nature. In addition, it's impacted by jacking of the inflowing of Changjiang River and Wujiang River as well as the backwater of the narrow reach in flood season. On the whole river, both Suspended load and gravel bed load it silts in the flood season and scouring in the course of landing after flood, it's in the basic balance of erosion and deposition in the year. Compared with the waterway topographic maps in many years we can see that there is little change in the river

bed, and the river erosion and deposition has little change [1]. In the 29 years from 1967 to 1996, 1.638 million m^3 are washed away in about 16 km long river in Fuling, the average riverbed undercutting is 0.17 m in 29 years, with an annual average of less than 0.01 m. According to another research result of Nanjing Hydraulic Research Institute[6], since March 1980 to March 1985 of five years, there is just 710,000 m^3 washed away since the stream Huangcao Gorge exports to the market of about 45.5 km long river of Fuling, the average is Less than 20,000 m^3 per kilometer, the average riverbed undercutting is 0.05 m in 5 years, with an annual average of 0.01 m. Overall, the whole river regime and the thalweg both keep stable basically while the patterns changes little in plane, and over the years, the shoreline is also basically stable. According to another statistics from December 1996 to March 2003, the total amount of deposition is 17 million m^3 from the dam to Qingxichang with the average of 34 thousand m^3/km, in which medial shoal and beach washed away 10 million m^3 while the silting amount of main channels is 27 million m^3, and these are all in the performance of " scouring in beaches and silting in troughs" but both are not of large amount. It shows that the year-to-year erosion and deposition is basically balanced before impounding of the Three Gorges reservoir area

Table1 The amount of scour–and–fill in Fuling reach

period	1967~1996	1980~1985	1967~1999	1967~2003
Amount of Silting and Scouring ($10^4\times m^3$)	-163.8 （16km）	-71.0 (45.5km)	+77.7 (16km)	-227.3 （15km）
Intensity of Silting and Scouring ($10^4\times m^3$/km)	-10.2	-2.0	+4.9	-15.2
Amplitude of River Bed Silting and Scouring (m)	-0.17	-0.05	`+0.08	-0.25

notes:“-”means scouring and “+” means silting. Follows are the same as this.

4 Analysis on river bed silting and scouring after utilization of Three Gorges Project

4.1 Characteristics of reservoir inflowing runoff and sediment after utilization of Three Gorges Project

Taking cuntan and wulong station as reservoir inflowing water and sediment controling station of the Yangtze river main channels and the branch of Wujiang river respectively, the characteristics of reservoir inflowing water and sediment before and after the impounding of the Three Gorges Reservoir is analyzed, which are showed in table2.

In 2006, the amount of inflowing runoff from upper stream of the Yangtze river is lower, runoff amount of Cuntan station is 247.9 billion m^3, about 28 percent less than the annual average value before impounding; suspended load amount is 26.6 billion t, 47 percent less than the annual average value. Runoff from Wujiang river is sharp declined, runoff amount of Wulong station is 26.6 billion m^3, 47 percent less than the annual average value before impounding; suspended load amount is 3.4 million t, 88 percent less than the annual average value.

Compared with 2006, the amount of inflowing runoff of Yangtze river in 2007 is more plentiful, runoff amount of Cuntan station is 312.4 billion m^3, about 9 percent less than the annual average value before impounding; suspended load amount is 210 million t, 51 percent less than the value. Inflowing amount of runoff of Wulong station

is 52.5 billion m^3, 5 percent more than annual average value before impounding; suspended load amount is 10.4 million t, 62 percent less than the annual average value.

Within 5-year operation of the Three Gorges Project (TGP), the amount of inflowing sediment has a great reduction both in Cuntan and Wulong station, the annual runoff is 323.2 billion m^3 and annual sediment load is 198 Million t in Cuntan station from 2003 to 2007, while they have a reduction of 6% and 53.9% than the inter annual average value respectively; the annual runoff is 42.7 billion m^3 and annual sediment load is 14.4 million t in Wulong station from 2003 to 2007, while they have a reduction of 14.8% and 47.2% than the inter annual average value respectively.

Table2 the inflowing runoff and sediment statistics of the reservoir area of TGP

Station	item	item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total	Stat. year
Cuntan	runoff (10^8m^3)	I	91	73	85	116	205	352	645	612	557	382	195	123	3438	1956～2002
		2006	114	96	127	107	187	285	447	227	290	313	161	121	2479	
		2007	108	76	82	98	146	290	651	501	544	335	173	120	3124	
		II	105	83	104	118	191	331	583	516	532	359	182	127	3232	2003～2007
		III	15.4	13.7	22.4	1.7	-6.8	-6.0	-9.6	-15.7	-4.5	-6.0	-6.7	3.3	-6.0	
	Sediment load (10^4t)	I	45	28	42	195	1139	4583	13877	11507	8232	2746	512	121	43025	1953～2002
		2006	48	22	84	45	394	1291	5330	720	1384	1337	135	77	10868	
		2007	55	27	29	37	346	1216	7794	5062	5132	1090	172	52	21000	
		II	39	23	43	93	429	1800	6958	4371	4543	1292	180	62	19833	2003～2007
		III	-13.3	-17.9	2.4	-52.3	-62.3	-60.7	-49.9	-62.0	-44.8	-52.9	-64.8	-48.8	-53.9	
Wulong	runoff (10^8m^3)	I	12	11	17	33	64	91	89	58	44	40	27	16	501	1951～1956、1983～2002
		2006	11	16	2	26	50	42	27	18	15	22	20	17	266	
		2007	18	18	21	36	38	79	111	76	57	34	22	15	525	
		II	14	13	15	28	57	71	76	43	39	29	22	17	427	2003～2007
		III	16.7	18.2	-11.8	-15.2	-10.9	-22.0	-14.6	-25.9	-11.4	-27.5	-18.5	6.3	-14.8	
	Sediment load (10^4t)	I	1	2	9	92	416	810	748	323	201	91	27	3	2724	1951～1955、1984～2002
		2006	2	3	4	33	161	83	13	4	6	14	3	11	338	
		2007	6	8	14	34	137	179	479	111	48	13	5	2	1040	
		II	1	1	2	37	134	474	678	36	62	7	3	4	1438	2003～2007
		III	0.0	-50.0	-77.8	-59.8	-67.8	-41.5	-9.4	-88.9	-69.2	-92.3	-88.9	33.3	-47.2	

Notes:"I" means: Annual Average Value before impounding, "II" means: Annual Average Value after impounding, "III" means: the discrepancy of Annual Average Value between before and after impounding(%).

4.2 Silting and scouring changes of riverbed after operation of three gorges reservoir

4.2.1 changes of thalweg

According to the fixed cross-section statistics in March 2003, the lowest elevation of thalway is 42.8 m in the fluctuating backwater area of the river reach between Fengdu and Lidu before impounding, which

locates near to Mopanshi (S248), is 444.6 km away from the dam. While the highest elevation is 129.6 m, locates near to Yong-an-chang (S258), is 468.0 km away from the dam. It is greatly wavy of thalweg, the difference of elevation highest and lowest point is 86.8 m. The thalweg shows sawtooth forms in longitudinal section along the reach.

After impounding, it presents silting trend in longitudinal section, except that a few cross-sections have greater depositions; thalweg elevation changes little at the great majority of the sections; the river bed still shows sawtooth forms, the characteristics of longitudinal section morphology have not fundamentally changed.

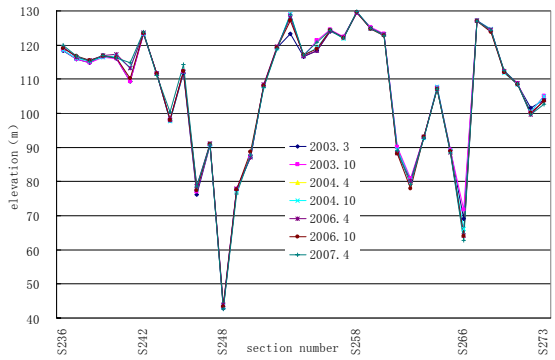

Fig.2 The longitudinal profile of Fengdu to Lidu reach

4.2.2 Changes of silting and scouring amount of river reach

From 2003 to 2006, the reservoir ran under impounding period of 135m to 139m Water Level, and is in impounding period of 156m after the floods in 2006. Sediment silting and scouring laws are different at different water levels, seeing table 3 and table 4.From the table we can see that the basic sediment silting and scouring law in the river reach of Fengdu to Lidu river is scouring in up-steam and silting in down-stream, silting in wide-shallow reach and scouring in narrow reach. It is generally silting in this river reach, a total deposition amount of 7.4 million m^3 has accumulated from 2003 to 2007, the average amount is 91 thousand m^3/km. silting is primarily occurred on the marginal bank and the deposition is cumulated. The deposition amount is 9.096 million m^3 in 80.89 km long river reach between Fengdu and Fuling from 2003 to 2006, while it is 12.266 million m^3 from 2003 to 2007. It silts less in the river main channels, during the same period the deposition amount is 5.096 million m^3. For the influencing of the less water and sand year of 2006, total scouring quantity is 4.866 million m^3 in the main trough of the entire river reach from 2003 to 2007.

Seeing from the subsection condition, the sediment silting and scouring shows the law of silting in down-stream and the silting little and even having some scouring in up-stream. 19.21km longth river in Fengdu reach(S236~S245) performances as accumulated silting, the cumulative deposition of each unit reach is 544,000 m^3/km. The river reach of Tunaozi(S252 ~ S255) is one of the three severe sediment depositing shoals in Chuanjiang reach, the annual deposition amount is just little than Chouyanqi, Lanzhuba before impounding. Within the impounding period of 135~139 m, the river reach of Tunaozi is in the reservoir fluctuating backwater area, the water level was raised by 1.0 ~ 5.5 m and the current velocity decreases of about 7 to 80 percent than that before impounding, the river bed primarily performances cumulated silting.

Within the impounding period of 144 ~ 156 m in 2007, this reach is in the upstream of perennial backwater area, the water level was raised by 3.5 ~ 12 m, the current velocity decreases of about 17 to 95 percent than that before impounding. With the development of sediment silting, in 2007 the average cumulative silting amount reaches to 1.386 million m^3/km; while in river reach of S266~S273, which is 37.31km long, primarily

performances scouring and the average scouring amount is 217,000 m^3/km in 2007.

Table3 sediment silting and scouring statistics of the river reach between Fengdu and Liduhe from 2003 to 2006

river reach	S236～S245	S245～S252	S252～S255	S255～S266	S266～S273	The whole course
Length of the river reach（km）	19.21	17.53	6.84	22.6	14.71	80.89
Full section（10^4m^3）	669.6	17.4	832.6	-146.9	46.5	1419.2
marginal bank（10^4m^3）	183.5	77.9	316.3	418.6	-86.7	909.6
Major trough（10^4m^3）	486.1	-60.5	516.3	-565.5	133.2	509.6
Silting and scouring amount of unit river length（10^4m^3/km）	34.9	1.0	121.7	-6.5	3.2	17.5

Table4 sediment silting and scouring statistics of the river reach between Fengdu and Liduhe from 2003 to 2007

Each river reach	S236～S245	S245～S252	S252～S255	S255～S273	The whole course
Length of the river reach（km）	19.21	17.53	6.84	37.31	80.89
Full section（10^4m^3）	1044.2	-555.4	948.1	-808.2	740.0
marginal bank（10^4m^3）	600.2	66.2	389	59.9	1226.6
Major trough（10^4m^3）	444	-621.6	559.1	-868.1	-486.6
Silting and scouring amount of unit river length（10^4m^3/km）	54.4	-31.7	138.6	-21.7	9.1

4.2.3 Silting and scouring law of cross section

Sediment scouring and silting changes of typical cross-sections are shown in Figure 3. Overall, it shows the characteristics of silting in wide-shallow reach and scouring in narrow-deep reach, e.g. the beach and deep trough are both silted in the wide-shallow profile S241; while it is scouring in the narrow-deep profile S246. Generally speaking, it is silting in the downstream sections while scouring in upstream sections, e.g. it has obvious erosion in the trough of the S273 section.

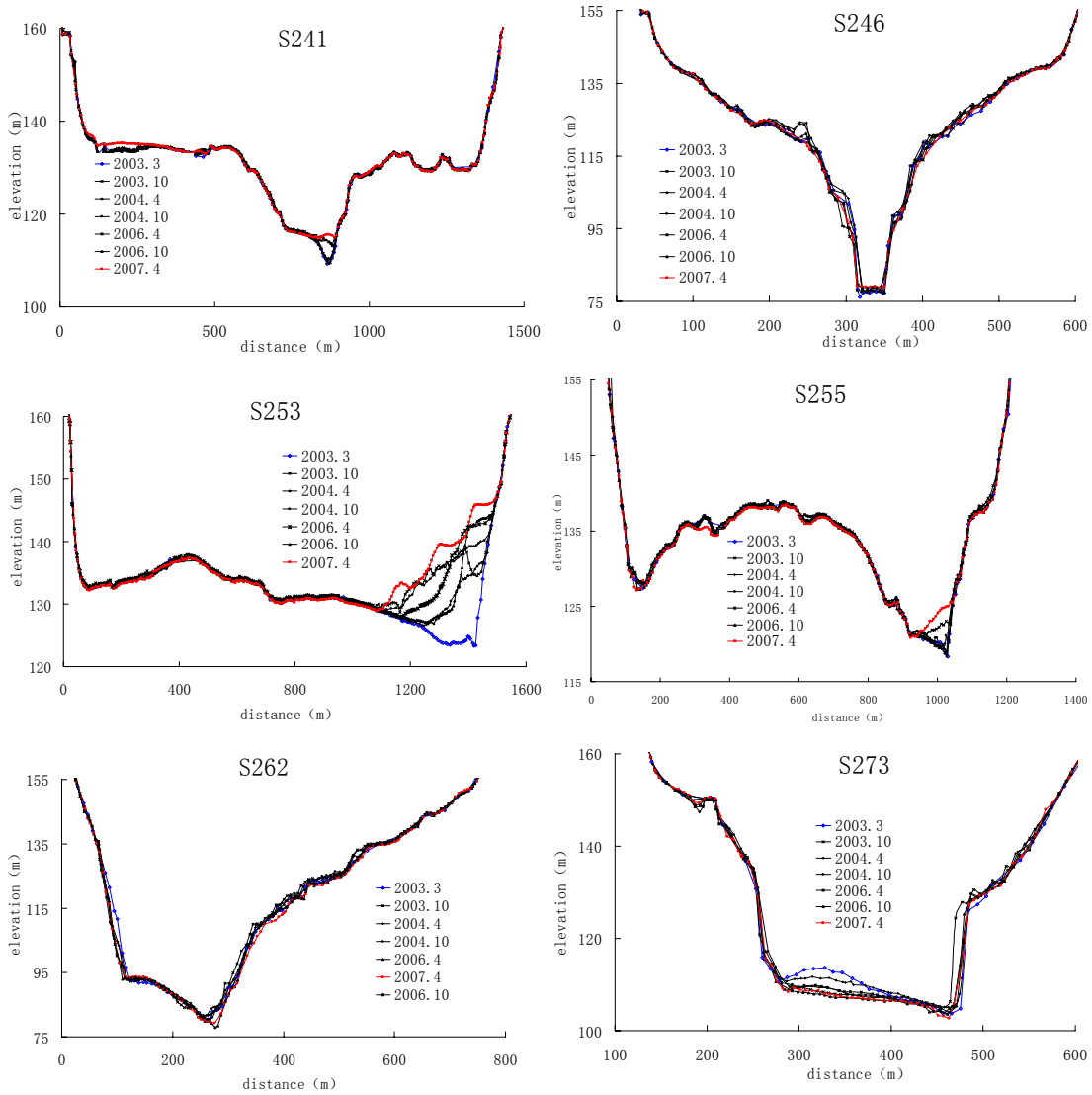

Fig.3 scour-and-fill of tipical cross-sections

It is noticeable that there has been generally cumulated deposition inter-annually along the right side of the deep trough in Tunaozi reach and the river regime has changed. As the river reach of Tunaozi is restricted by the boundary condition before and after impounding, bank line is basically stable and the river regime is still keeps curve, but the deposition is cumulated inter-annually along the right side of the deep trough after impounding and local deep quirk has been filled up with deposition, while the silting deformation of moraine dam along the left bank is small. Significant changes have taken place in pattern of cross-section, for instance, the ratio of wide to deep is increased significantly; deep trough in concave bank and moraine dam in convex bank(e.g. braided cross sections which are left shallow and right deep and in “V” shape)has changed into “U” shape cross sections at present; with further raising of water level of the Three Gorges, river bed elevation near the concave bank will not have major changes, while the silting near convex bank will grow, deep trough will be in concave bank again(e.g. River regime will transit gradually from the curve of deep trough in convex bank to the curve of deep trough in concave bank).

5 Analysis on trend of river bed evolution

The river reach was in the reservoir fluctuating backwater area during the impounding period of 156m-NWL (normal water level) and it is in reservoir perennial backwater area of 175m-NWL where the level will be raised by 3~10.5m in flood season and about 39m in low water season. For small boulder amount from the upper stream of Yangtze river and Wujiang river, after construction of the Three Gorges reservoir the boulder bed load in Yangtze river main channels is estimated to silt mainly over the urban area of Chongqing city(in the upstream of Dadukou reach), the main effect on bed-building will be conducted by the fine sand in suspended sediment.

During the impounding period of 156m, the river reach between Fengdu and Lidu still maintains the basic natural silting and scouring law in flood season, the silting location of suspended sediment deposition is also basically the same but after bloods the "taking sand" period postpones to April or May of the following year, the amount of suspended sediment deposition in the flood season is slightly larger than nature; for raising of the water level after floods, the original law of “silting in floods and scouring after floods” has change; current velocity was slowed down and the year-to-year sediment deposition represents a cumulated-growing trend. After the impounding period of 175m in front of the dam, the river reach has been in the perennial backwater area and the water level is greater than the natural condition. With the development of sediment silting of this reach and down-stream of the dam, the water level raised value will be greater. During the impounding period of 175m, suspended sediment have silted largely; with the accretion of sediment silting and the reservoir utilization year, the deposition will be higher and thicker in primary silting area and then the speed of the sediment siltation will be gradually slowed up. With the accretion of the reservoir utilization year, the water level of Fuling river reach will keep raising gradually , the deposition is still accumulated and becomes higher and thicker in the previous primary silting area, but the speed of the sediment siltation will be gradually slowed up than before. After the reservoir have utilized for 50 years, river silting form is similar to that after 30 years. The watercourse in reservoir area will show the elemental trend as evaluating to a singles, regular and slightly curving course. According to the sediment model experiment research results of Fuling reach and adopting the runoff and sediment series from 1961 to 1970[7] [8], silting amount in each unit reach will be 544 thousand m^3/km in 2009 and it will be 479.7m^3/km and 670.9m^3/km after the reservoir utilization of 30 years and 50 years respectively. Three significant characteristics of river bed evolution after siltation, are ：□ The watercourse will evaluate to a single, regular and slightly curving course in plane；□ The former compound section evaluates to unify one in transverse section. it is silted both in the beach and trough while most of the sediment silts on the beach and the deposition is more in the convex bank of curves；□ Difference in elevation of the deep trough which is rather wavy formerly is less in longitudinal section.

The annual runoff of Cuntan station in 10 years from 1961 to 1970 is $3690\times10^8m^3$ and the annual sediment load is 4.83×10^8t ,while the annual runoff and sediment load of this station from 2003 to 2007 is 12.4 percent and 59 percent less than that respectively. The annual runoff of Wulong station in this 10 years is $503.8\times10^8m^3$ and the annual sediment load is 0.281×10^8t ,while the annual runoff

and sediment load of this station from 2003 to 2007 is 15.2 percent and 48.8 percent less than that respectively. With the starting working in succession and putting into action of a great number of large and media reservoirs in the upstream of Yangtze river, increase trend e.g. the annual sediment amount owning to silt trapping of reservoir is 5890×10^4t from 1956 to 1990 while it is up to 12510×10^4t from 1991 to 2005, occupying 51 percent of the total inflowing sediment amount reduction of the Three Gorges Project[9]. The silt trapping of reservoir will becoming more significant for the building of a serious of large reservoir in succession such as Xiluodu , Xiangjia dam, Wudongde, Baihetan and Tingzikou etc. in recent years.Therefore, the reservoir inflowing sediment will decrease in quite a long period, the speed of the sediment siltation is little than prediction while silting and scouring law of this river reach will not change in whole.

6 Conclusion:

(1) The coastline of the river reach is irregular and alternates with wide and narrow river width. The variety of watercourse silting and scouring is little before the operation of the Three Gorges Reservoir and the river bed is in slow downcutting in a long period.

（2）Comparing with that before the reservoir is built,the amount of the reservoir inflowing sediment of Cuntan and Wulong station has reduced within the 5 years operation of three gorges reservoir. The annual runoff and sediment load of Cuntan station from 2003 to 2007 is 6 percent and 53.9 percent less than the annual average value respectively, while Wulong station is 14.8 percent and 47.2 percent respectively.

(3) The silting and scouring law of the river reach between Fengdu and Lidu is that scouring in the upper and narrow-deep reach and silt in the down and wide-shallow reach in principle. It is generally silting in this river reach and the deposition is cumulated on the marginal bank, while it has little siltation or even some scouring in the trough. The deposition is cumulated alongside the right trough of Tunaozi shoal and the river regime of which has been changed.

（4）With the development of the sediment siltation, the watercourse will evaluate to a single, regular and slightly curving course. Due to the significant decrease of the reservoir inflowing runoff and sediment and the silt trapping of up-stream reservoir, the reservoir inflowing sediment will decrease in quite a long period, the speed of the sediment siltation is little than prediction while overall silting and scouring law of this river reach will not change.

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