Analysis on the law of sediments deposition in the three gorges reservoir

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Abstract. Since the impoundment of the Three Gorges Reservoir, there were always sustainable deposition, and by December 2015, it was a total of 1 billion 604 million t. Deposition mainly concentrated in the perennial backwater area downstream of Qingxichang station, the deposit amount is 1 billion 486 million t, accounting for 92.7% of the total sedimentation amount; the deposit amount of Qingxichang to Zhutuo section is 118 million t, accounted for 7.3% of the total sedimentation amount. After the impoundment of Three Gorges Reservoir into the 175m trial in 2008, the scope of deposition exhibits extension, the deposit amount of Qingxichang to Zhutuo section increases obviously. The spatial distribution of deposition is related to the channel width and the distance from the dam, deposition in front of the dam and the gully section of Fengjie to Fuling is the largest, while the deposition occurs in 2008 to 2010 in the upstream of Fuling, and it turns to scour after 2010.

1. Introduction

Three Gorges Dam is located in Zigui County, Yichang City, Hubei Province. June 2003 to September 2006 the reservoir was operated in accordance with the scheme of 135m to 139m, from October 2006 to September 2008, 156m to 144m scheme was adopted. In 2008, at the end of the flood season, tried 175m impoundment, the highest water level in the year was 172.8m. In October 2010, the water level in front of the dam reaches 175m for the first time, backwater to reached Honghuaqi reach in Jiangjin District, Chongqing City, reservoir area has a length of about 664km; fluctuation area is Jiangjin to Fuling section of Chongqing, a length of about 173.4km, accounting for 26.3% of the total length of the reservoir; perennial backwater area is from Fuling to the dam, has a length of 486.5km, accounting for 73.7% of the total length of the reservoir[1,2].

2. Deposition distribution analysis based on the transport rate method

Since the incoming sediment of Three Gorges Reservoir(TGR) relatively much less than the value of preliminary design, the rate of deposition is reduced greatly[3,4,5]. According to the hydrological observation data statistics from three main control stations(see Figure 1), such as Table 1 , in June 2003 to December 2015, the incoming suspended sediment of TGR is 2.1152 billion t, and the flushing value is 0.5118 billion t(Huanglingmiao Station). While not considering interval sediment incoming, the total amount of deposition is 1.6034 billion t, annually approximately 0.128 billion t, and the flushing ratio of sediment is 24.2%. Deposition mainly concentrated in the perennial
backwater area downstream of Qingxichang station, the deposit amount is 1.486 billion t, accounting for 92.7% of the total sedimentation amount; the deposition amounts of Zhutuo to Cuitan and Cuitan to Qingxichang section are 0.037 billion t and 0.811 billion t, accounting for 2.3% and 5.1% of the total sedimentation amount respectively.

After the impoundment of TGR into the 175m trial in 2008, the total deposition amount is 0.963 billion t, the flushing ratio of sediment is 17.28%. The deposition amounts of Zhutuo to Cuitan and Cuitan to Qingxichang sections are 0.037 billion t and 0.0717 billion t, accounting for 3.84% and 7.44% of the total sedimentation amount respectively, while the deposition amount of the reach between Qingxichang and the dam accounting for 88.72% of the total sedimentation amount. It can be seen that after the impoundment of TGR into the 175m scheme, the deposition ratio of the reservoir tail increases especially the reach of Cuitan to Qingxichang.

3. Sediment deposition distribution based terrain

Since the impoundment of the TGR, the accumulative amount of deposition of mainstream in reservoir area is 1 452.1 million m³ during March 2003 to December 2015, including 53.6 million m³ erosion in fluctuating backwater area, and 1 505.7 million m³ deposition in perennial backwater area.

| Time (year) | Incoming Flushing sediment | Total deposition amount | Deposition amount of different reaches/Ratio of the deposition amount to the total value | Flushing ratio of sediment |
|-------------|---------------------------|-------------------------|---------------------------------------------------------------------------------|----------------------------|
| 2003.6~2003.12 | 20810 8400 12410 | / / 4950 39.9% 4950 39.9% 7460 60.1% | 40.4% |
| 2004 | 16600 6370 10230 | / / 3630 35.5% 6600 64.5% | 38.4% |
| 2005 | 25400 10300 15100 | / / 4890 32.4% 10210 67.6% | 40.6% |
| 2006 | 10210 891 9320 | / / 590 6.3% 4790 51.4% 3940 42.3% | 8.7% |
| 2007 | 22040 5090 16950 | / / 370 2.2% 9610 56.7% 6970 41.1% | 23.1% |
| 2008 | 21780 3220 18560 | / / 2870 15.4% 8420 45.4% 7270 39.2% | 14.8% |

Table 1. Deposition of the Three Gorges reservoir. Unit: 10⁴t
### 3.1. Fluctuating backwater area

The fluctuating backwater area was natural reach and kept fluvial equilibrium every year before 2008. After then the reach had scoured due to the coming sediment decreasing and Sand Excavation. While, under the influence of the impoundment of the TGR, the scouring has decreased from upstream to downstream. 

JiangJin to entrance of Jialing River in Chongqing, (S343+1 ~ CY15, 40.5km long), the accumulate erosion is 39.447 million m³ during October 2008 to October 2015, and there are 1 million m³/km per unit length.

Entrance of Jialing river to TongLuoXia section (CY15 ~ S273, 11km long), in the same period, the amount is 1.2 million m³, 0.11 million m³/km per unit length; TongLuoXia to LiDu town section (S273 ~ 323, 98.9km long), the amount is 13.362 million m³, 0.135 million m³/km per unit length, which is equal to upper section.

LiDu to FuLing section (S267 ~ 118), in the initial impoundment of the Three Gorges Reservoir with 175m trial, with the operation water-level in front the dam increases constantly, sediments deposition (Ds) in this reach has enlarged. During March 2003 to October 2015, the accumulation deposition amount is 0.9388 billion m³, and 2.977 million m³/km per unit length (Sediments Deposition /Length, Ds/L). Refer to Fig.2, the Ds/L of Zhong Xian to FengDu section, YunYang to Wan Xian section, WanXian to Zhong Xian section are largest, which are 4.218 million m³/km, 4.182 million m³/km, and 4.168 million m³/km, respectively.

FengJie to MiaoHe section (S118 ~ S40-1), this reach is 156km long, including narrow river with the length of 81.4km and wide river with length of 74.6km. During the same period with upper reach, the Ds of this reach is 405 million m³ and Ds/L is 2.596 million m³/km, which are most distributed in main channel. Refer to Tab.3, the largest accumulate deposition strength is in BaiDiCheng to GuanDaoXia section (14.2km long), which is 99.967 million m³ and Ds/L is 7.04 million m³/km, only second to the reach near the dam. and most distribute in ChouYanQi reach with larger river width. Next is reach between ZiGui to GuanDuKou section, with 150.097 million m³ and 3.277 million m³/km.

Miao He to Dam section (S30+1 ~ 40-1), it is junction area of fluctuating backwater and perennial backwater, during March 2003 to October 2015, the accumulation erosion amount is 0.804 million m³, and there are 64 thousands m³/km per unit length. The scouring range is little.

### 3.2. Perennial backwater area

FuLing to FengJie Section (S267 ~ 118). In the initial impoundment of the Three Gorges Reservoir with 175m trial, with the operation water-level in front the dam increases constantly, sediments deposition(Ds) in this reach has enlarged. During March 2003 to October 2015, the accumulation deposition amount is 0.9388 billion m³, and 2.977 million m³/km per unit length (Sediments Deposition /Length, Ds/L). Refer to Fig.2, the Ds/L of Zhong Xian to FengDu section, YunYang to Wan Xian section, WanXian to Zhong Xian section are largest, which are 4.218 million m³/km, 4.182 million m³/km, and 4.168 million m³/km, respectively.

FengJie to MiaoHe section (S118 ~ S40), this reach is 156km long, including narrow river with the length of 81.4km and wide river with length of 74.6km. During the same period with upper reach, the Ds of this reach is 405 million m³ and Ds/L is 2.596 million m³/km, which are most distributed in main channel. Refer to Tab.3, the largest accumulate deposition strength is in BaiDiCheng to GuanDaoXia section (14.2km long), which is 99.967 million m³ and Ds/L is 7.04 million m³/km, only second to the reach near the dam. and most distribute in ChouYanQi reach with larger river width. Next is reach between ZiGui to GuanDuKou section, with 150.097 million m³ and 3.277 million m³/km.

Miao He to Dam section (S30+1 ~ 40-1). It is near to the dam with length of 15.1km. it deposition 161.73 million m³ totally, and 10.71 million m³/km, which is the most deposition strength reach since the impoundment of the TGR.
Figure 2. Deposition strength of each reach in perennial backwater area

Table 2. Sedimentation in mainstream of the Three Gorges reservoir area

| Cross section          | Number       | Distance     | 1996.12 ~ | 2003.03 ~ | 2006.10 ~ | 2008.10 ~ | 2015.10 ~ | 2003.03 ~ |
|------------------------|--------------|--------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Miaohe-Dam             | Dam~S40-1   | 15.1         | 214       | 7418      | 3179      | 5575.8    | 16172.8   |
| Zigui-Miaohe           | S40-1~S49   | 16.5         | 154       | 1744      | 567       | 1443      | 3754      |
| Guandukou-Zigui        | S49~S70     | 45.8         | 614       | 8041      | 2720      | 4248.7    | 15009.7   |
| Wushan-Guandukou       | S70~S93     | 44           | 177       | 1954      | 1574      | 1471.4    | 4999.4    |
| Daxi-Wushan            | S93~S107    | 28.8         | 314       | 3332      | 1200      | 1642.7    | 6174.7    |
| Baishicheng-Daxi       | S107~S111   | 6.7          | 74        | 60        | 245       | 262.6     | 567.6     |
| Guandaoxia-Baishicheng | S111~S118   | 14.2         | 223       | 4805      | 1557      | 3634.7    | 9996.7    |
| Yunyang-Guandaoxia     | S118~S142   | 53.6         | 464       | 1209      | 13        | 2115.8    | 3337.8    |
| Wanxian-Yunyang        | S142~S172   | 66.7         | -540      | 8155      | 4643      | 15093.1   | 27891.1   |
| Zhongxian-Wanxian      | S172~S214   | 81.2         | -228      | 11289     | 4589      | 17963.3   | 33841.3   |
| Fengdu-Zhongxian       | S214~S242   | 58.8         | 473       | 6329      | 3696      | 14778.9   | 24803.9   |
| Fuling-Fengdu          | S242~S267   | 55.1         | -225      | 197       | -27       | 3838.2    | 4008.2    |
| Lidu-Fuling            | S267~S273   | 12.5         | Non       | -169      | 82        | 6.6       | -80.4     |
| Tongluoxia-Lidu        | S273~S323   | 98.9         | 984       | -2320.2   | -1336.2   |           |           |
| Dam- Lidu              | Dam~S273    | 499          | 1714      | 54365     | 24036     | 72074.8   | 150476.8  |
| Dam-Tongluoxia         | Dam~S323    | 597.9        | 25020     | 69754.6   | 149140.6  |           |           |

Refer to Figure 2, the deposition strength of the reservoir isn’t increasing from the upstream to downstream, while it appears the distribution trend of “increase-decrease—increase”, under the influence of increasing of water depth and change of river width. Tab.3 provides theDs in different reach patterns. The deposition most distributes in wide valley reach, with yield accounting for 93.95 percent of perennial backwater area, and strength of 4.7 times to narrow gorge reach.
Tab.3 Sedimentation in different river patterns of mainstream in reservoir  Unit: $10^4 \text{m}^3$

| CS          | No. | W/N | L   | 2003-03.03-06.09-09.09-10.09-10.10-10.11-10.12-10.13-10.14-10.2003-03.06-06.09-09.09-10.09-10.10-10.11-10.12-10.13-10.14-10.15-10.15.10 |
|-------------|-----|-----|-----|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Dam-Grundukou | Dam~S70~ | W  | 77.4 | 17203 | 6466 | 3963 | 1219 | 676 | 1963 | 1220 | 2078 | 149 | 34937 |
| Guandukou- Wushan | S70~S93 | N  | 44  | 1954 | 1574 | 954 | -13 | 392 | -413 | 228 | 269 | 55 | 5000 |
| Wushan-Daxi | S93~S107 | W  | 28.8 | 3332 | 1200 | 760 | -16 | 152 | 328 | 10  | 204 | 205 | 6175 |
| Daxi-Baidicheng | S107~S111 | N  | 6.7 | 60 | 245 | 109 | 7  | 83 | -59 | 68  | 11  | 45 | 568 |
| Baidicheng- Guandaoxia | S111~S118 | W  | 14.2 | 4805 | 1557 | 1063 | 518 | 339 | 423 | 480 | 677 | 134 | 9996 |
| Guandaoxia- Yunyang | S118~S142 | N  | 53.6 | 1209 | 13  | 1101 | 514 | 383 | -1145 | 1434 | -436 | 264 | 3337 |
| Yunyang-Fuling | S142~S267 | W  | 261.8 | 25970 | 12901 | 16004 | 11814 | 5478 | 9608 | 9504 | 137 | -872 | 90544 |
| Fuling-Lidu | S267~S273 | N  | 12.5 | -169 | 82 | -122 | 213 | 175 | -132 | 12  | -49 | -90 | -80 |
| Dam-Lidu | Dam~S273~499 | 54364 | 24038 | 23832 | 14256 | 7678 | 10573 | 12956 | 2891 | -111 | 150477 |
| Total | % | 76.6 | 94.4 | 92.0 | 90.9 | 93.5 | 86.1 | 118 | 85.8 | 112.7 | 117.1 | 93.9 |

4. Conclusions
Since the impoundment of the Three Gorges Reservoir, there were always sustainable deposition, and by December 2015, it was a total of 1 billion 604 million t. Deposition mainly concentrated in the perennial backwater area downstream of Qingxichang station, the deposit amount is 1 billion 486 million t, accounting for 92.7% of the total sedimentation amount; the deposit amount of Qingxichang to Zhutuo section is 118 million t, accounted for 7.3% of the total sedimentation amount. After the impoundment of Three Gorges Reservoir into the 175m trial in 2008, the scope of deposition exhibits extension, the deposit amount of Qingxichang to Zhutuo section increases obviously. The deposition is related with distance from dam and the width of the reach, the most deposition per unit length is the section nearby the dam and the wide section from Fengjie to Fuling.

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