Characteristics of a far-dam channel evolution downstream of the Three Gorges Reservoir

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Abstract. Due to the influence of distance, there is a lag effect of channel erosion and deposition in the far reaches of the lower reaches downstream from the reservoir. In this paper, the scouring and silting characteristics of Wuhan reach in the middle and lower reaches of the Yangtze River after the impoundment of the Three Gorges Reservoir was analysed based on the five times plane topographic data. The results show that although there is some scouring in this reach at the beginning of the impoundment of the Three Gorges Reservoir, the intensity is not large. With the increase of the operation time of the Three Gorges Reservoir, the scour gradually develops to this reach, and the scour intensity increases greatly, but it is still concentrated in the basic channel.

1. Introduction
After the operation of the Three Gorges project, there is a long-distance scouring and silting response in the downstream of the dam [1]. Different from the near dam reach, the far dam reach is affected by the upstream sediment recovery [2], and the response of riverbed scouring and silting has a certain lag [3]. Therefore, the characteristics of the riverbed are different from those of the reach near the dam. In-depth study of its historical response characteristics is helpful to grasp the time response characteristics of riverbed change to reservoir operation [4]. Based on the analysis of the scouring and silting characteristics of the far dam reach, Wuhan reach since the impoundment of the Three Gorges Reservoir, this paper has summarized the response characteristics of the far dam reach to the changes of water and sediment conditions.

2. Study area, data and method

2.1. Study area
Wuhan reach, from Shamao mountain to Yangluo, is located in the middle reaches of the Yangtze River, about 630 km away from the Three Gorges Reservoir. The Hanjiang flows into this section. Due to the node control and the implementation of revetment engineering on both sides of the river, the plane shape of the river has been basically stable since the 1930s, and the change of shoreline on both sides of the river is relatively small. There is Tianxingzhou in the middle of the river. In the 1950s, the left branch of Tianxingzhou was the main branch, and the diversion ratio was about 60% and the sediment distribution ratio was about 63% in dry season. Then, with the change of upstream river regime and the change of erosion and deposition of Tianxingzhou branch, the left branch gradually shrank, the diversion and sediment distribution ratio decreased, the South Branch gradually developed, and the diversion and sediment distribution ratio increased. At the end of 1960s and the beginning of 1970s, the diversion ratio of the right branch was more than 50% and became the main branch, and the sediment diversion ratio
was about 50%. By the late 1970s, when the low flow is less than 10000 m³/s, the diversion ratio is more than 90%, and the sediment distribution ratio is also more than 85%. Since the mid-1980s, the flow of the left branch has been basically cut off in the low flow period, but the diversion ratio in the flood season is still more than 30%. The location and geomorphology of the study reach are shown in Figure 1.

Figure 1. Location of the study area and its geomorphology.

2.2. Data
In this paper, a total of five river terrain observation data were collected, which were carried out in October 2002, October 2006, October 2011, October 2013 and October 2016. All measurements were carried out by the Bureau of hydrology of the Yangtze River Water Resources Commission.

2.3. Method
In this paper, the quadrilateral mesh is used to divide the river bed terrain. Firstly, the terrain elevation of each vertex of quadrilateral mesh is interpolated according to the river terrain scattered points by using a Delaunay interpolation method [5]. According to the quadrilateral vertex elevation after interpolation, the erosion and deposition amount of quadrilateral was calculated.

3. Results

3.1. Amount of sediment deposition & erosion
Table 1 shows the amount of scouring and silting under different elevations, and Figure 2 shows the comparison of the amount of scouring and silting under flat and above flat. It can be seen that the deep channel below 0 m has silted up, and the channel above 0 m has scoured in the initial stage of impoundment. From 2001 to 2013, the scour volume of the whole reach is about 61.905 million m³. After 2013, the scour of this reach intensified. From 2013 to 2016, the scour amount reached 85.639
million m$^3$ which was about 1.4 times of the previous 12 years. The channel above the bank-full level has little change and slight erosion. The accumulated erosion is only about 1.02 million m$^3$ and the average erosion thickness is less than 0.1m.

Table 1. Scouring and silting amount of river bed at different elevations.

| Elevation (m) | 2001–2006 | 2006–2011 | 2011–2013 | 2013–2016 |
|--------------|-----------|-----------|-----------|-----------|
| -10          | 37.6      | -56.9     | 21.5      | -20.5     |
| -5           | 451.6     | -598.3    | 227.0     | -540.9    |
| 0            | 486.9     | -1249.3   | 198.3     | -3733.5   |
| 5            | 287.8     | -2511.7   | -1470.2   | -7972.1   |
| 10           | 370.8     | -3222.5   | -2488.1   | -9357.8   |
| 15           | -505.7    | -3068.5   | -2243.7   | -8974.3   |
| 20           | -891.2    | -3020.3   | -2216.9   | -8550.7   |
| 25           | -1234.3   | -2884.4   | -2071.9   | -8563.9   |

Figure 2. The amount of scouring and silting below and above bank-full level.

3.2. Distribution and characteristics of scouring and silting in shoal and channel

Figure 3 shows the distribution of erosion and deposition in different periods. It can be seen from the Figure 3 that during the studied period, the Wuhan reach is mainly scoured, and the scour is mainly concentrated in the main channel with a general scour amplitude of about 1-3m. And the local scour depth is relatively large. For example, the local scour depth can reach about 7m from 2011 to 2013 near the confluence of Hanjiang River. The beach on both sides of the main channel is slightly silted, but the siltation range is generally small, within 1m, and up to 3 ~ 5m in some areas. From the distribution of siltation, the siltation is mainly distributed in head of Tianxingzhou and the left branch. This is unfavourable to the development of the left branch, which may cause the further shrinkage of the left branch and bring adverse effects on the flood discharge of the river.
Figure 3. The distribution of scouring and silting at different elevations in different periods.

4. Conclusions
Based on five times of topographic observation data of Wuhan reach before and after the impoundment of the Three Gorges Reservoir, the amount and distribution of erosion and deposition of the study reach in different periods were analysed in this paper. The results show that due to the long distance from the Three Gorges Reservoir, the local deep channel of Wuhan reach has silted up in the early impoundment period of the Three Gorges Reservoir, and the basic flow channel is scoured as a whole, but the intensity
is not large. After 2013, the scouring intensity of this reach increased, but the scouring was still concentrated in the basic flow channel. The scouring amount of the reach above the bank-full water level was small, and the average scouring intensity was less than 0.1m.

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