Analysis of Scouring and Silting Changes in the Middle and Lower Reaches of the Yangtze River after the Three Gorges Project Operation

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Abstract. The annual runoff of the middle and lower reaches of the Yangtze River has little change before and after the Three Gorges Project is put into operation, but the annual distribution of runoff has changed, and the sediment discharge of the reach has fallen in a cliff-like manner. The application of the Three Gorges Project has changed the scouring and silting situation of the main stream and the two lakes, making them change from silting to scouring direction, causing the water level of the rivers and lakes to drop. The changes of scouring and silting conditions, flow velocity, water depth and water level have a certain impact on the survival and reproduction of the four major domestic fish, porpoise and waterfowl. In order to protect the fragile aquatic ecosystem from the adverse effects of the operation of the Three Gorges Project, this paper puts forward three suggestions, namely, the delimitation of protected areas of top priority, the spatial management and control of river and lake shorelines, and the ecological scheduling, which is of great significance to the scientific decision-making of the water administrative department in the process of protection of the Yangtze River.

1. Introduction

There are large areas of wetlands in the middle and lower reaches of the Yangtze River, mainly including rivers, lakes and riverbank wetlands. As an important part of the water ecosystem in the middle and lower reaches of the Yangtze River, wetland play an important role in maintaining ecological balance, providing habitats for animals and plants, protecting biodiversity, and providing necessary animal and plant resources for human survival and reproduction [1].

Wetland is an important part of the earth's surface ecosystem. It is a natural synthesis with special functions formed by the interaction of land and water, and its response to hydrological process is very sensitive [2,3]. Since the completion of the Three Gorges Dam, due to the regulation and storage of the Three Gorges reservoir, the conditions of water and sediment from the middle and lower reaches of the Yangtze River have changed. The impoundment operation of the Three Gorges reservoir has changed the hydrological situation of the main stream, tributaries and lakes and wetlands of the Yangtze River. At the same time, due to the intercepting effect of the reservoir on the upstream sediment, the clear water has been discharged for quite a long time, which has caused the changes of the downstream channel sediment erosion and deposition, changed the river situation and the relationship between rivers and the lakes [4], which may have a certain impact on the structure and function of the water ecosystem in the middle and lower reaches of the Yangtze River [5,6]. Therefore,
this paper briefly introduces the impact of the Three Gorges Project on the hydrology, water and sediment processes in the middle and lower reaches of the Yangtze River, and selects key river sections and two lakes to identify the degree of changes in river and lake sediment erosion and deposition before and after the operation of the Three Gorges Project. Finally, based on the reduction of important biological resources such as finless porpoise and waterfowl after the operation of the Three Gorges project, the paper puts forward countermeasures for the protection of the water ecosystem in the middle and lower reaches of the Yangtze River.

2. The influence of the Three Gorges Project on the hydrologic and sediment processes in the middle and lower reaches

2.1 Operation mode of the Three Gorges Project

The Three Gorges project is located in the middle section of Xiling Gorge of the Yangtze River, the control basin area is 1 million square kilometer, annual average runoff is 451 billion cubic meter and annual average sediment discharge is 530 million ton. The designed normal water level is 175 m, the total storage capacity is 39.3 billion cubic meter and the flood control capacity is 22.15 billion cubic meter.

The operation of the Three Gorges project is a key measure to deal with the flood control problems in the middle and lower reaches of the Yangtze River, and it has brought huge comprehensive economic benefits in power generation, shipping, water supply and the development of the reservoir economy. According to the regulation for cascade operation of the Three Gorges (normal operation period) - Gezhouba Water Control Project, the water level of the Three Gorges water control project in flood season is controlled by 145.0m of flood control limit water level. During the real-time operation, the water level of the reservoir can change within a certain range of the flood control limit water level. The impoundment time of the Three Gorges project should not be earlier than September 10. When the water level of Shashi station and Chenglingji station is lower than the warning water level (43.0m and 32.5m respectively), and the forecast does not exceed the warning water level in the short term, the impoundment plan can be implemented. Generally, on September 10, the water level of the Three Gorges reservoir is not higher than 150.0m, and the control water level at the end of September is 162.0m. With the consent of the national defense general, the water level at the end of September can be adjusted to 165.0 m according to the water situation, and 175.0 m at the end of October. From 175.0m to the end of the year, the Three Gorges reservoir should maintain high water level operation as much as possible. In the real-time operation, the need of weekly regulation and daily peak regulation can be taken into account, and appropriate amplitude should be reserved below 175.0m. From January to May of the following year, the water level of the Three Gorges Reservoir gradually subsided under the condition of comprehensive consideration of shipping, power generation, water resources and water ecological demand. Generally, the water level of the reservoir at the end of April shall not be lower than 155.0m, and on May 25 shall not be higher than 155.0m. In case of extremely low water year, the emergency operation of water resources may not be limited by the above water level and flow.

2.2 Influence of Three Gorges project operation on hydrological process

The trend of annual runoff in the middle and lower reaches of the Yangtze River is not significant before and after the operation of the Three Gorges project. Compared with the period before the Three Gorges project operation from 1960 to 2002, the annual runoff of typical representative stations in the middle and lower reaches of the Yangtze River after the operation of the Three Gorges project was reduced by 5% - 8%, as shown in Table 1, and the annual runoff of the upper reaches of the Yangtze River was also reduced by about 8% compared with the annual runoff between 1950-2002. On the premise that the impact of water vapor cycle change in the Three Gorges Reservoir area is ignored, it can be considered that the operation of the Three Gorges Project on the annual runoff of the middle and lower reaches of the Yangtze River is not significant. In recent years, the decrease of annual
runoff in the middle and lower reaches of the Yangtze River is mainly caused by the decrease of inflow in the upper reaches of the Yangtze River.

### Table 1. Average annual runoff of stations in the middle and lower reaches of the Yangtze River before and after the operation of the Three Gorges Project

| Period       | Runoff/100 million m³ |
|--------------|------------------------|
|             | Yichang    | Shashi     | Hankou     | Datong     |
| 1960-2002   | 4369       | 3942       | 7112       | 9052       |
| 2003-2015   | 4005       | 3760       | 6711       | 8438       |
| Compared with the runoff between 1960-2002 /% | -8% | -5% | -6% | -7% |

However, the operation of the Three Gorges project has a greater impact on the annual distribution of runoff in the middle and lower reaches of the Yangtze River. The operation of the Three Gorges project has changed the annual inner diameter flow process in the downstream of the dam. Through the comparison of the annual average daily flow process of Hankou station in 1952-2002 and 2003-2015, as shown in Figure 1, it is found that after the impoundment of the Three Gorges reservoir, the runoff process of Hankou station is more uniform, the proportion of runoff increases in the dry season and decreases in the flood season, but the period of flood recession becomes shorter and the water process becomes steeper.

![Figure 1. Annual average daily flow process of Hankou Station before and after the operation of the Three Gorges Project](image)

### 2.3 Influence of Three Gorges project operation on hydrological process

Compared with that before the operation of the Three Gorges Project from 1950 to 2002, the annual sediment transport observed by the main hydrological stations in the middle and lower reaches of the Yangtze River decreased significantly from 2003 to 2015. It decreased by 67% - 91% along the way, as shown in Figure 2.
Figure 2. Variation of annual average sediment transport at stations in the middle and lower reaches of the Yangtze River before and after the operation of the Three Gorges Project

Sediment transport in the lower reaches of the Three Gorges project changes significantly before and after the operation of the Three Gorges Project. Before the operation of the Three Gorges reservoir, the trend of sediment transport along the course decreases gradually from the upstream to the downstream, but increases gradually after the operation. This shows that the riverbed scours along the course after the operation of the Three Gorges project, and the sediment concentration of the lower reaches of the river has recovered.

3. Changes of erosion and deposition in the main stream of the Yangtze River

3.1 Changes of typical sections

Since the operation of the Three Gorges reservoir, the main channel has been cut down. The section form of Yichang station is irregular "U" shape. The section changes of erosion and deposition and riverbed are still in constant adjustment. Compared with 2002, the section changes little in 2010. The cross section of Zhicheng station is irregular "V" shape. Compared with 2002, the low flow channel was scoured seriously in 2010, and the lower part of the channel is nearly 13 M. The section form of Shashi station is irregular "W" shape. Compared with 2002, the low flow channel and flat beach were scoured by current at the same time in 2009, especially the channel, whose elevation decreased nearly 15 m. Like Shashi station, the section form of Luoshan station is also irregular "W" shape, but the section is scoured by beach silting channel, and the amount of scour is mainly concentrated in the low flow channel, and the riverbed is silted between the low flow and the flat water level, which leads to higher beach with large height and lower channel with small elevation. The sections of Hankou station and Nanjing station are all irregular "U" shape, and the river channel is also scoured to different degrees, but the scour degree of the river channel is smaller than that of Zhicheng station and Shashi station, as shown in Figure 3.
3.2 Changes of deep channel profile

After the operation of the Three Gorges project, the plane form of the middle reaches of the Yangtze River is still generally stable, but the evolution of the local river regime caused by the development of the deep channel of the riverbed and the swing of the main stream line is still in adjustment. The riverbed in the middle reaches of the Yangtze River is dominated by the longitudinal scouring depth. From October 2002 to October 2011, the scouring depth from Yichang reach to Zhicheng reach was cut down 3.6 m on average and the maximum scouring depth was 18.0 m.

The reach from Zhijiang to Chenglingji is the closest sandy reach to the Three Gorges reservoir, which is affected by the discharge of "clear water" from the Three Gorges reservoir. It scoured violently in this reach, but the overall river regime is basically stable. Since the Three Gorges reservoir
operation, the vertical profile of Jingjiang river channel has been scoured and silted alternately, which is mainly manifested in the deep scour depth of bend, branch or transition section at the upstream of bend and branch, and the change of the elevation of the straight section is relatively small, as shown in Figure 4. In October 2015, the vertical elevation of the upper Jingjiang deep elevation decreased significantly compared with that in 2002, and the maximum deep elevation of the reach decreased by 13 m, while that of the Lower Jingjiang deep elevation decreased and increased compared with that in 2002. The average scour depth of Jingjiang river reach is 1.4m, the maximum scour depth is 13.8m, and the cross section of some riverbed changes violently.

![Figure 4. Changes of deep channel profile in the Jingjiang channel](image)

Since the operation of the Three Gorges reservoir, the reach from Chenglingji to Hankou has been scoured, as shown in Figure 5. From November 2003 to November 2015, the longitudinal section of deep elevation in the reach from Chenglingji to Hankou was scoured and silted alternately. Generally, it was mainly scoured and undercut, with an average of 0.75m. Among them, the scour depth of the section, transition and near the bridge was relatively large, such as the maximum scour depth in nannenzhoutou and Wuhan Yangtze River Bridge, which were 15.1m and 7.2m respectively. There was siltation near the curve section, such as Chibi. The maximum siltation height near the bay is 1.5m and 1.2m respectively, and the other siltation amplitude is relatively small.

In addition, due to the comprehensive influence of the Three Gorges Reservoir and other factors, Chengtong reach is also dominated by scouring undercutting, with an average scouring undercutting of 0.75 m and a maximum scouring depth of 15.4 m, as shown in Figure 6.

![Figure 5. Changes of deep channel profile in the channel from Chenglingji to Hankou](image)
Changes of erosion and deposition in Dongting Lake and Poyang Lake

4.1 Changes of erosion and deposition in Dongting Lake
From 1956 to 2015, the annual sediment inflow and outflow of Dongting Lake showed a downward trend, especially after the application of the Three Gorges Project. Before the operation of the Three Gorges project, the annual average sediment inflow of Dongting Lake was 123.5 million ton per year, and after the operation of the Three Gorges Project from 2003 to 2015, it decreased to 0.96 million ton per year, decreased by 92.2%; before the operation of the Three Gorges project, the annual average sediment inflow of the four waters of Dongting Lake was 28.2 million ton per year, and after the operation of the Three Gorges Project from 2003 to 2015, it decreased to 8 million ton per year, decreased by 71.6%. Therefore, after the Three Gorges project is put into operation, the amount of sediment from three outlets and four waters drops precipitously. Compared with the four waters, the amount of sediment from three outlets has a larger drop. The proportion of sediment from three outlets into the lake has also dropped from 81.4% before the Three Gorges Project was put into operation in 1956-2002 to 54.0% after the Three Gorges project was put into operation in 2003-2015. In general, the annual sediment inflow of Dongting Lake before the operation of the Three Gorges Project from 1956 to 2002 was 151.7 million ton per year, which decreased to 176.6 million ton per year from 2003 to 2015, decreased by 88.4%, and the sediment inflow into the lake decreased significantly, as shown in Table 2.

Table 2. Analysis of sediment inflow and outflow of Dongting Lake in different periods

| Period     | sediment entering the lake/100 million t•a⁻¹ | sediment leaving the lake/100 million t•a⁻¹ | erosion and deposition/100 million t•a⁻¹ |
|------------|---------------------------------------------|------------------------------------------|------------------------------------------|
|            | Sankou Sishui total proportion/%            |                                          |                                          |
| 1956—2002  | 1.235 0.282 1.517 81.4 0.393 1.124         |                                          |                                          |
| 2003—2015  | 0.096 0.08 0.176 54.0 0.192 -0.016         |                                          |                                          |

From 1956 to 2002, the average annual sediment yield of Dongting Lake was 39.3 million ton per year, before the operation of the Three Gorges Project. From 2003 to 2015, the annual sediment yield of Dongting Lake decreased to 19.2 million ton per year, decreased by 51.1%, far less than that of Dongting Lake. The dynamic change of sediment inflow and outflow of Dongting Lake has caused the change of the situation of erosion and deposition of Dongting Lake. Before 2002, the area of Dongting Lake was dominated by sedimentation, with an average annual sedimentation of 112.4 million ton per
year, from 2003 to 2015, the area of Dongting Lake showed a trend of erosion, with an average annual erosion of 16 million ton per year.

4.2 Changes of erosion and deposition in Poyang Lake
From 1956 to 2002, the average annual inflow and outflow sediment of Poyang Lake were 14.25 million ton per year and 9.91 million ton per year respectively, the inflow sediment was larger than the outflow sediment, and the average annual deposition sediment in the lake area was 4.34 million ton per year; after the operation of the Three Gorges Project from 2003 to 2015, the average annual inflow and outflow sediment of Poyang Lake were 4.97 million ton per year and 12.1 million ton per year respectively, the inflow sediment was smaller than the outflow sediment, and the average annual erosion sediment in the lake area was 7.13 million ton per year. As shown in table 3, which also includes the sand mining volume of river channel.

| Period       | Sediment entering the lake/100 million t•a⁻¹ | Sediment leaving the lake/100 million t•a⁻¹ | Erosion and deposition/100 million t•a⁻¹ |
|--------------|---------------------------------------------|--------------------------------------------|----------------------------------------|
| 1956—2002    | 1425                                        | 991                                        | 434                                    |
| 2003—2015    | 497                                         | 1210                                       | -713                                   |

5. Analysis of the impact of the Three Gorges Project on the water ecosystem in the middle and lower reaches of the Yangtze River
After the operation of the Three Gorges Project from 2003 to 2015, during September to November, the reservoir impoundment, the reservoir discharge decreased, the water level of the main stream and the outlet control stations of the two lakes in the middle and lower reaches decreased, and the low water appeared in advance; during December to may, the Three Gorges project played the role of storing and supplementing the low water, the low water flow of each station in the middle and lower reaches increased, and the water level rose accordingly, and the operation of the Three Gorges project changed the hydrological situation of the middle and lower reaches of the Yangtze River. In addition, the clear water discharge of the Three Gorges reservoir will cause the scour of the river and lake bed, change the water depth and water level of the main stream reach, Dongting Lake and Poyang Lake in the middle and lower reaches of the Yangtze River, and have a certain impact on the habitat and reproduction of aquatic organisms and water birds in the middle and lower reaches of the Yangtze River\(^7\).

The four great fishes in the middle reaches of the Yangtze River have valuable germplasm resources, but since the application of the Three Gorges project, their early resources have declined year by year. Suitable water rising conditions and water temperature are important conditions for the natural reproduction of tetradoxylus. Serious gas supersaturation may threaten the survival of tetradoxylus eggs and juveniles\(^8\). The operation of the Three Gorges project makes the flow process in the middle and lower reaches of the Yangtze River tend to be gentle, which changes the water rising conditions on which the four great fishes depend for reproduction. At the same time, the clear water discharged from the Three Gorges Reservoir scour the river and lake bed, reduces the water level, increases the water depth, changes the physical characteristics of the four great fishes spawning ground\(^9\), and has a certain impact on the population activities of the four great fishes.

The Yangtze River finless porpoises generally live in groups near the Yangtze River beach. The riverway and the side beaches of the two lakes in the middle and lower reaches of the Yangtze River have typical habitat characteristics of finless porpoises\(^10\). However, after the application of the Three Gorges project, the scour balance of the river / lake bed in the middle and lower reaches of the Yangtze River has changed, and the scour effect of the river / lake bed has become prominent, which has changed the habitat environment of finless porpoises to a certain extent, and has a negative impact on the habitat and reproduction of finless porpoises. Influence.
In addition, the survival of waterfowl is also affected by the operation of the Three Gorges Project. There are two main aspects. One is that the operation of the Three Gorges Project causes the migration of rare birds to miss the opportunity of food exposure; the other is that the water surface of the main habitat depression of rare birds is reduced. These two aspects lead to the reduction of food in the habitat, which seriously threatens the food supply of waterfowl and has an important impact on the survival and reproduction of waterfowl. Ring\cite{1}.

6. Protection Countermeasures of water ecosystem

After the application of the Three Gorges project, the habitats of aquatic organisms and waterfowls in the middle and lower reaches of the Yangtze River are facing serious threats, so it is urgent to take relevant measures to protect the water ecosystem on which human beings and aquatic organisms depend. This paper mainly puts forward three suggestions, namely, the delimitation of priority protection areas, the spatial management and control of river and lake shorelines, and the ecological regulation.

6.1 Delimitation of priority reserves

In view of the habitats of endangered species in the middle and lower reaches of the Yangtze River and the areas where important habitats such as aquatic organisms and waterfowls have changed significantly before and after the Three Gorges project is put into operation, priority protection zones are designated to protect the habitat environment from human activities.

6.2 Strengthen the spatial control of river and lake shoreline

Strictly control the water ecological space such as water area and coastline, delimit the management scope of rivers and lakes, water project management scope and protection scope according to laws and regulations, and clarify the management responsibilities. We will implement zoning management and use control of the water coastline, strengthen the protection, conservation and intensive use of the coastline, and scientifically divide the water coastline protection areas, reserved areas, restricted development areas and development and utilization areas. In view of the shoreline of the waters around the important habitat of aquatic organisms and waterfowls, it is included in the scope of water shoreline protection zone, the construction project permission is strictly controlled, and it is strictly prohibited to set up sewage outlets, and to some extent, the restoration of the aquatic habitat under the influence of the Three Gorges project operation is carried out to ensure the effective protection of the important water ecosystem in the middle and lower reaches of the Yangtze River.

6.3 Implement ecological scheduling

The change of hydrological process in the middle and lower reaches of the Yangtze River under the operation of the Three Gorges project has an important impact on the spawning and reproduction of the four great fishes. Therefore, in order to simulate the natural flow in the river, it is necessary to put forward the ecological regulation scheme of the three Gorges reservoir which is conducive to the spawning and reproduction of the four great fishes, so as to ensure that the water discharge conditions of the reservoir meet the spawning needs of the four great fishes.

7. Conclusion

Before and after the operation of the Three Gorges project, the trend of annual runoff in the middle and lower reaches of the Yangtze River is not significant. However, the operation of the Three Gorges project has a greater impact on the annual distribution of runoff in the middle and lower reaches of the Yangtze River. In addition, after the operation of the Three Gorges project, the sediment discharge of the river section decreased in a cliff like manner. The clear water discharge of the Three Gorges project has changed the scour and deposition situation of the main stream and the two lakes, making them change from siltation to scour direction, causing the water level of the rivers and lakes to drop. Among them, the scour and deposition situation of different river sections varies greatly due to the
influence of local river situation, distance from the Three Gorges project, human activities and other factors.

The changes of scour and deposition conditions, flow velocity, water depth and water level caused by the operation of the Three Gorges project have a certain impact on the survival and reproduction of the four great fishes, finless porpoises and waterfowls. In order to protect the fragile water ecosystem from the adverse effects of the operation of the Three Gorges project, it is urgent to define priority protection areas, implement spatial control and ecological scheduling of river and lake shorelines.

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