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Effects of Three Gorges Reservoir (TGR) water storage in June 2003 on Yangtze River sediment entering the estuary

Z. X. Chu and S. K. Zhai

College of Marine Geosciences, Ocean University of China, Qingdao, 266003, China

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Correspondence to: Z. X. Chu (zhongxinchu@163.com)

Abstract

The world-greatest water conservancy project, Three Gorges Reservoir (TGR), stored water for the first time in June 2003, which provides an excellent opportunity to examine its effects on the sediment entering the Yangtze River estuary. A daily record dataset of water discharge and suspended sediment concentration (SSC) of the Yangtze River measured at Datong (the controlling hydrological gauging station into the estuary) from May 15 to July of 2003 spanning the water storage, together with a monthly record dataset of runoff, sediment load and SSC measured at Datong from 1953 to 2003, were used to examine the effects of the TGR water storage in June 2003 on the Yangtze River sediment entering the estuary. The results show that the unnaturally clearer water due to the TGR sedimentation resulted by the water storage in June 2003 brought the Yangtze River markedly decreased SSC and sediment load entering the estuary both during the TGR water storage and in the second half year of 2003.

The Yangtze River water and sediment discharges into the estuary from 15 May to 15 July in 2003 spanning the TGR water storage clearly indicated three phases: (1) pre-water storage of the TGR from 15 May to 25 May, during this phase, SSC and sediment load increased with water discharge increasing; (2) water storage of the TGR from 25 May to 10 June (including the preparation phase from 25 May to 31 May), during this phase, SSC and sediment load decreased dramatically with water discharge decreasing; and (3) post-water storage of the TGR, at the beginning, SSC, sediment load and water discharge basically remained at a relatively low value until the end of June, and since then, SSC and sediment load increased gradually with water discharge increasing. In addition, the real total sediment load was reduced by 2456.07×10^4 t than the estimated total sediment load during the period from 27 May to 2 July in 2003.

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1 Introduction

Human activities have been strongly affecting the world rivers sediment supply to the oceans since the 19th or 20th century (Stanley and Warne, 1993; Fanos, 1995; Smith and Winkley, 1996; Stanley, 1996; Yang et al., 2004). About 13% of all fluvial discharge is presently dammed (Pearce 1991), and moreover, rivers are being dammed at an increasing rate (Milliman and Syvitski, 1992). As a result, the decreased riverine sediment discharges due to human reasons especially dam constructions are the main cause for observed deltaic degradation processes world-wild (Stanley and Warne, 1993).

There are 85 153 reservoirs by the end of 2003 in China continent with the total water storage capacity amounting to 8658×10^8 m^3 (Ministry of Water Resources of China, 2003), and the number of dams higher than 15m in China by the end of 1972 amounts to 12517 (Han and Yang, 2003), accounting for about half of those in the world (Zhou, 2000). The impounded sediment in reservoirs has been a serious problem, and the total water storage capacity of reservoirs in China has decreased by 40% due to sedimentation (Wang and Lin, 2003).

The Yangtze River is the third longest (Wang and Zhu, 1994), fifth largest in water discharge, and forth largest in sediment load in the world (Eisma, 1998). The river sediment discharge into the sea is closely related to the evolution of the Yangtze River mouth, mouth bar, river delta, and deposition patterns of East China Sea (Qin, 1963; Milliman et al., 1985; Chen et al., 2000; Yang et al., 2003, 2006). On the other hand, the Yangtze River sediment features are also closely related to the particulate geochemical compositions (Martin and Meybeck, 1979; Zhang, 1999; Lin et al., 2002), which have important effects on ecosystem and environment in the estuary, coast, and even shelf areas (Zhang, 1999; Jiang and Yan, 2003).

The effects of the Three Gorges Reservoir (TGR) water storage on the Yangtze River sediment have aroused full attention in different fields. The project will surely bring about enormous benefits such as flood control, hydropower generation, and navigation,

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however, there are also many people (e.g., Li, 1992, 1993; Li et al., 1993; Jin, 1993) arguing that this project should give up or put off. The TGR will submerge two of the three world-famous gorges, along with irreplaceable cultural and archaeological sites. Nof (2001) even feared the TGR water storage, along with other water diversions in China, could significantly change the salt content of the Japan Sea, thereby impacting the climate there. Sediment research is one of the most important concerns about the TGR. The sediment study in the TGR region can be traced back to the 1950s (Hu, 2000), and is still continuing. Many scientists and departments have already examined sediment problem of the TGR via prototype observation, numerical modeling, or /and solid model experiment before the TGR water storage. Nevertheless, what on earth will be the effects when the TGR really stores water? The TGR water storage for the first time in June 2003 provides an excellent opportunity to resolve the question. This paper aims to examine the effects of the TGR water storage in June 2003 on the Yangtze River sediment entering the estuary.

2 Research background

The TGR on the Yangtze River, near Yichang (Fig. 1), formally commenced in December 1994, and the whole project is to be completed in 2009. When the reservoir reaches the pool level of 175 m, it will extend 600 km upstream, with a reservoir surface area of 1060 km^2, stretching from Yichang to Chongqing (Lu and Higgitt, 2001) and has a world-record hydropower capacity of 17 860 MW (Gao and Chen, 1994). The TGR (between Qingxichang and Huanglingmiaodou) stored about $100\times10^8 m^3$ water for the first time from 25 May to June 10 of 2003, elevating the pool level to 135 m (above mean sea level at Wusong located in Shanghai).

Some preparations for the TGR water storage were made from 25 May to 31 May in 2003 to reduce downstream water discharge, mainly by gradually adjusting diversion bottom outlets of the Gezhou Dam, about 40 km downstream the TGR dam. From 1 June to 10 June, the TGR Dam decreased downstream water discharge by alternating

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two or three diversion bottom outlets, which are the only passages for upstream riverine water through the TGR Dam before deep outlets opening. During this period, downstream water discharge from the TGR dam was often controlled at 2500~4900 $m^3 s^{-1}$ for downstream navigation. When the pool level reached 135.79 m on 10 June, thirteen deep outlets were gradually opened to increase downstream water discharge, and as a result, the water discharge at the outlet of the TGR was gradually balanced to that at the inlet. From then on, the TGR was in normal dispatching stage with the pool level ranging from 134.9 to 135.4 m until the end of flood season.

3 Data

A daily record dataset of water discharge and suspended sediment concentration (SSC) of the Yangtze River measured at Datong hydrological gauging station during the period from 15 May to 15 July of 2003 spanning the TGR water storage, together with a monthly record dataset of runoff, SSC and sediment load at Datong during the period 1953 to 2003, were collected from Changjiang Water Resources Commission.

Datong hydrological gauging station, about 1800 km downstream of the TGR dam (Fig. 1), is located at the tidal limit of the river mouth in dry season, covering about 94% of the drainage area. This station serves as the controlling station for the measurements of the Yangtze River water and sediment discharges into the estuary. It must be pointed out that the sediment data in this study were suspended sediment data. Previous study (Yang et al., 2002) showed that bed load at Datong, usually absent, is 0.044% of the total sediment load. So, suspended sediment load is dominant when compared with the bed load. In view of its dominance, suspended sediment was used to substitute for the total sediment in this study.

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4 Results

4.1 Daily change

4.1.1 Water discharge

During the period from 15 May to 29 May of 2003 within the flood season (from May to October), the Yangtze River water discharge at Datong gradually increased from 36 400 $m^3 s^{-1}$ on 15 May to the highest of 48 900 $m^3 s^{-1}$ on 29 May. Since 30 May, due to the TGR normal water storage, the water discharge dramatically decreased to the lowest of 32 800 $m^3 s^{-1}$ on 12 June, reduced by 16 100 $m^3 s^{-1}$ than the highest on 29 May. In fact, the difference of the Yangtze River water discharge at the outlet of the TGR (measured at Huanglingmiaodou about 13 km downstream the TGR dam, its location is in Fig. 1) between the highest (21 900 $m^3 s^{-1}$ on 14 June) and the lowest (3200 $m^3 s^{-1}$ on 10 June) during the period from 25 May to 12 June is 18 700 $m^3 s^{-1}$(unpublished). After the TGR normal water storage on 10 June, nevertheless, the water discharge entering the estuary basically remained about 35 000 $m^3 s^{-1}$ until the end of June (Fig. 2b). Since then, the water discharge delivering the estuary gradually increased, finally amounting to 61 400 $m^3 s^{-1}$ on 15 July. The water discharges measured at the outlet of the TGR (at Huanglingmiaodou) and at the inlet of the estuary (at Datong) are depicted in Figs. 2a and b.

4.1.2 Sediment load

The daily Yangtze River sediment loads at Datong were calculated by daily water discharge and SSC. The sediment load at Datong naturally increased during the period from 15 May to 26 May (Fig. 2c), from 55.35×10^4 t on 15 May to 127.90×10^4 t on 26 May. Since then, it dramatically decreased until amounting to 31.64×10^4 t on June 11. After the TGR normal water storage on 10 June, the sediment load basically remained at a low value ranging from 35 to 75×10^4 t until the end of June (Fig. 2c). From

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the beginning of July, the sediment load entering the estuary gradually increased to 137.57×10^4 t on 3 July, which is slightly larger than that (127.90×10^4 t) on 26 May, and finally reached 234.46×10^4 t on July 15.

During the period between 27 May and 2 July totaling 38 days, the daily river sediment load delivering the estuary was smaller than that on 26 May (Fig. 2c). Assuming the daily river sediment load during this period with an understated value of 127.90×10^4 t, which was measured on 26 May, the estimated total sediment load amounted to 4860.20×10^4 t ($127.90\times38=4860.20$). However, the real total sediment load during this period was only 2404.13×10^4 t, reduced by 2456.07×10^4 t than the estimated data. Actually, the sediment load entering the estuary tends to be increase from May to July according to historical data, and therefore, the estimated data of 4860.20×10^4 t sediment load entering the estuary during the period between 27 May and 2 July in 2003 should be understated.

4.1.3 SSC

The Yangtze River SSC and sediment load entering the estuary are closely related to the water discharge from 15 May to 15 July (Figs. 2b, c and d). Similarly to the tendency of sediment load, the SSC at Datong naturally increased, from 0.176 kg m^{-3} on 15 May to 0.309 kg m^{-3} on 26 May, and since then, it dramatically decreased to 0.108 kg m^{-3} on 10 June. After the TGR normal water storage on 10 June, the SSC basically remained at a low value ranging from 0.11 to 0.22 kg m^{-3} until the end of June (Fig. 2d). From the beginning of July, the SSC gradually increased, reaching 0.455 kg m^{-3} on 13 July.

4.2 Monthly change

4.2.1 Runoff

The Yangtze River monthly runoffs entering the estuary from June to December in 2003 did not change largely when compared with those in the corresponding months in 2002, 2001 as well as multi corresponding months averages (1953–2000) (Fig. 3a). As to the Yangtze River, the flood season includes months from May to October, and other months in the year belong to the dry season. The monthly runoffs within flood season from June to October are naturally larger than those within dry season from November to December (Fig. 3a). The largest monthly runoff in the seven months depicted in Fig. 3 in 2003 is 1480×10^8 m^3 in July, and the smallest is 310×10^8 m^3 in December. Although about 80×10^8 m^3 water was stored in the TGR (from Qingxichang to Huanglingmiaodou) during 1 June to 10 June in 2003 (unpublished), the monthly runoff in June 2003 is 970×10^8 m^3 only with slightly decrement when compared with that in July 2002 and the corresponding months average from 1953 to 2000.

4.2.2 Sediment load

The monthly sediment loads entering the estuary in 2002 and 2001 especially in 2003 were markedly smaller than the corresponding months averages from 1953 to 2000 (Fig. 3b). Due to 318×10^4 t suspended sediment was impounded in the TGR (from Qingxichang to Huanglingmiaodou) during 1 June to 10 June (unpublished), the sediment load in June 2003 is only 1610×10^4 t, which is significantly smaller than those in 2002, 2001 and the corresponding months average (Fig. 3b). As mentioned above, the real total sediment load was reduced by 2456.07×10^4 t than the estimated total sediment load during the period between 27 May and 2 July, which also explained the decreased sediment load in June 2003. The larger runoff in July 2003 (Fig. 3a) led to slightly larger sediment load (Fig. 3b) despite smaller SSC (Fig. 3c) in the same month, when compared with those in the same months in 2002 and 2001, but it is still far smaller than the multi-months average in July from 1953 to 2000. Very smaller SSC led to very smaller sediment load in October 2003. About 1.2365×10^8 t suspended sediment was impounded in the TGR from June to December in 2003 (unpublished), and as a result, generally, monthly sediment loads in 2003 after the TGR water storage in June 2003 are some smaller than those in 2002 and 2001 as well as the corresponding months averages from 1953 to 2000.

4.2.3 SSC

Generally, the monthly SSCs entering the estuary in 2003, 2002 and 2001 are some smaller than the corresponding months averages from 1953 to 2000 (Fig. 3c). The monthly SSC in June 2003 is 0.17 kg m^{-3}, smallest in months within flood season from June to October and still larger than those within dry season from November to December. Due to a large of suspended sediment depositing in the TGR resulted by the TGR water storage, the monthly SSCs in the second half year of 2003 are very small, ranging from 0.12 kg m^{-3} to 0.36 kg m^{-3}.

5 Concluding remarks

The Yangtze River water and sediment discharges into the estuary from 15 May to 15 July in 2003 spanning the TGR water storage in June 2003 clearly indicated three phases: (1) pre-water storage of the TGR from 15 May to 24 May, this phase was characterized by natural conditions, i.e. SSC and sediment load increased with water discharge increasing; (2) water storage of the TGR from 25 May to 10 June (including the preparation phase from 25 May to 31 May), during this phase, SSC and sediment load decreased dramatically with water discharge decreasing; and (3) post-water storage of the TGR after 10 June, at the beginning, SSC, sediment load and water discharge remained at a relatively low value until the end of June, and since then, SSC and sediment load increased gradually with water discharge increasing. The Yangtze

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River SSC, sediment load and water discharge delivering the estuary indistinctively increased from 11 June to 14 July (Figs. 2b and c), although the TGR dam output the natural upstream water after the water storage on 10 June, which is probably due to the buffering and resultantly hysteresis processes by the 1800 km-long stretch between the TGR dam and the estuary.

Generally, although the monthly runoffs of the Yangtze River entering the estuary from June to December in 2003 did not change largely, the monthly SSCs and sediment loads were clearly reduced, when compared with those in the corresponding months of 2002 and 2001 as well as the corresponding months average from 1953 to 2000.

There are three large inputs joining the Yangtze River 1800 km-long channel between the TGR dam and the estuary: Lake Dongting, Han River and Lake Poyang (their locations are in Fig. 1). However, about 50% of the Yangtze River water and nearly all its sediment entering the estuary originate from the uplands upstream from the TGR Dam, which has a catchment area of 100×10^4 km^2 (55.6% of the whole drainage basin) (Chen et al., 2001). So, the Yangtze River markedly decreased SSC and sediment load entering the estuary since the TGR water storage is undoubtedly attributed to the TGR sedimentation resulted by the TGR water storage despite the regulation by the 1800 km-long river stretch between the TGR dam and the estuary.

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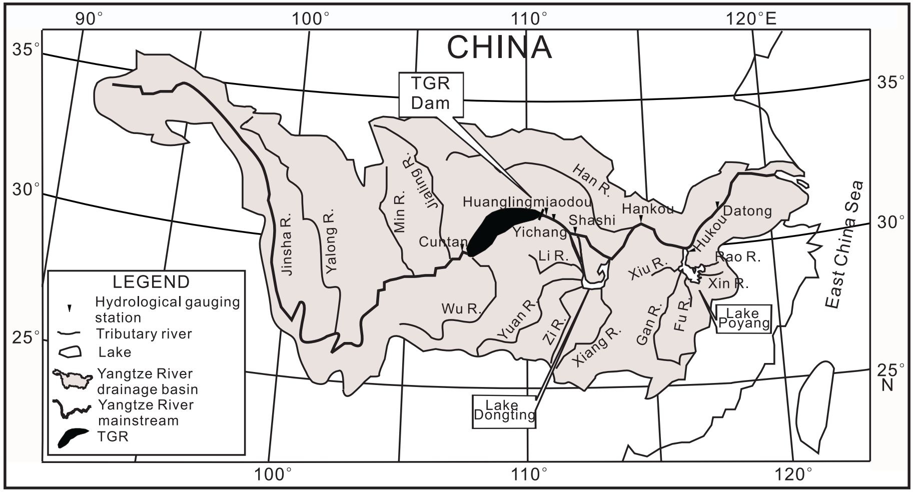

Fig. 1. Location map of the Three Gorges Reservoir (TGR) in the Yangtze River drainage basin, major tributaries, interior lakes, and hydrological gauging stations.

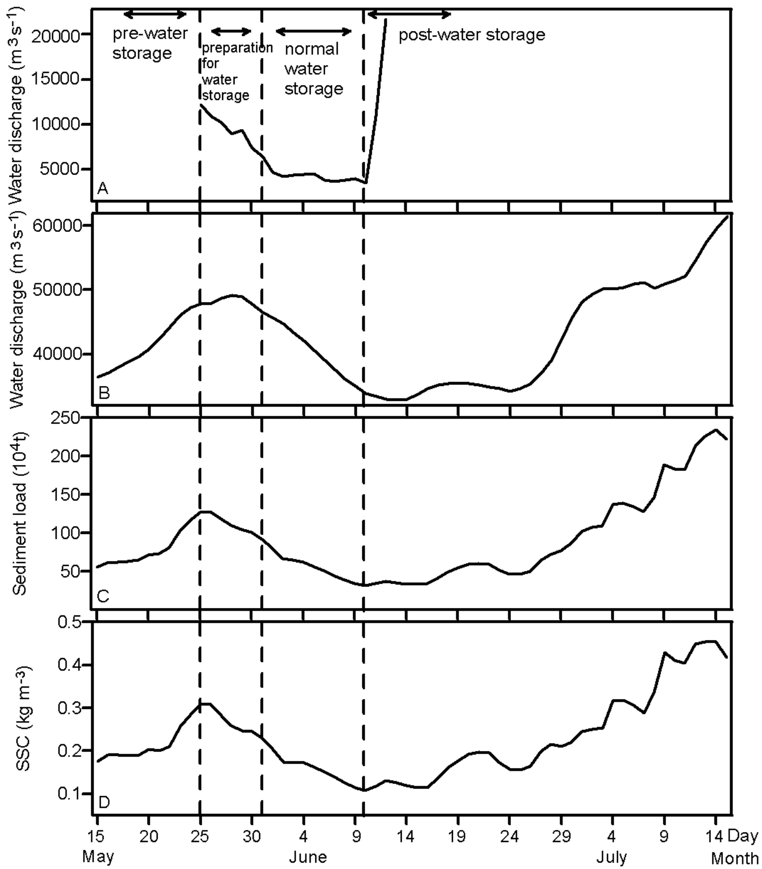

Fig. 2. Daily water discharge **(a)** at Huanglingmiaodou station about 13 km downstream the TGR dam, water discharge **(b)**, sediment load **(c)** and SSC **(d)** at Datong station of the Yangtze River from 15 May to 15 July in 2003 spanning the TGR water storage. Note: the significantly decreased water discharge, sediment load and SSC during the TGR water storage from 1 June to 10 June.

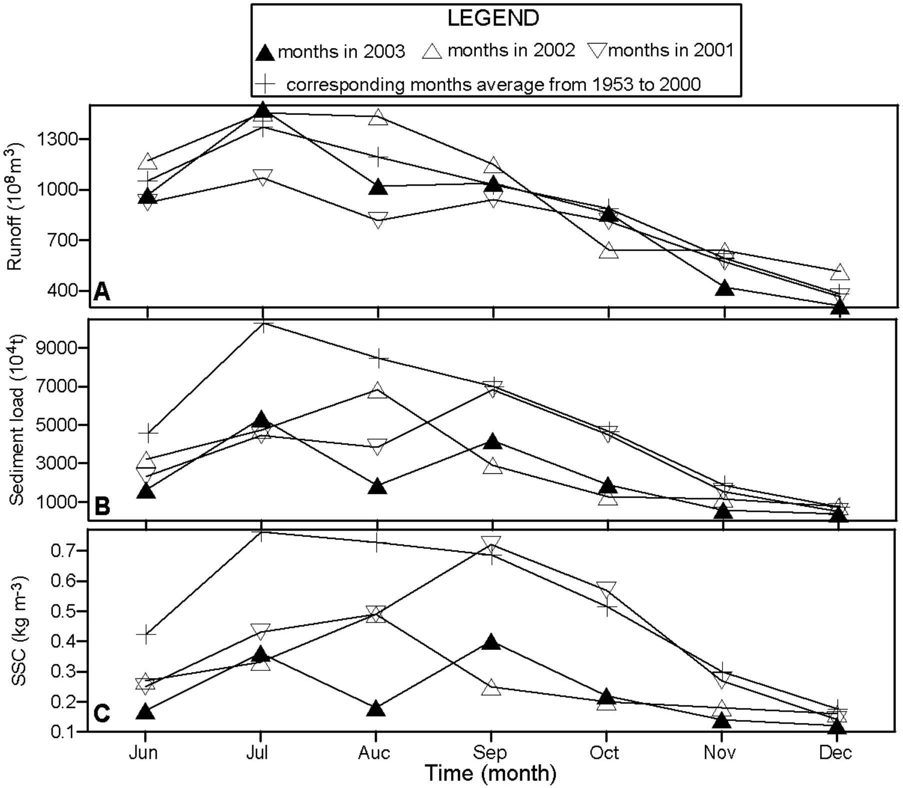

Fig. 3. Monthly runoff **(a)**, sediment load **(b)**, and SSC **(c)** of the Yangtze River at Datong station from June to December in 2003, 2002 and 2001 as well as the averages from 1953 to 2000.

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