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RESERVOIR SEDIMENTATION MANAGEMENT IN CHINA

BY WENHONG CAO, CHUNJING LIU & LEILEI GU

Chinese reservoirs face severe sedimentation problems due to the heavy sediment load of the rivers in north China. Long-term management of sediment accumulation for sustainable use of reservoirs has become essential part of the effort to solve water shortage issues. With nearly 70 years of efforts dealing with reservoir sedimentation, especially in the Yellow river region, which has the highest annual sediment transport load in the world, China has got extensive experience upon which to draw lessons. This article summarizes lessons learned on sediment inflow reduction measures, reservoir operation modes and technologies for recovering totally, or partially the reservoir storage capacity. The article is complementary to other articles in this and previous issues of Hydrolink on reservoir sedimentation, such as those by Kondolf and Schmitt, Annandale *et al.*, Kantoush and Sumi, Lyoudi *et al*. Wang and Kuo, who present diverse experiences and policies in managing reservoir sedimentation.

Silting of Chinese dams: facts

There are 98,795 reservoirs (as of 31 December 2017) with a total capacity of 941 billion m^3 in China. These reservoirs not only supply water to 22% of the world's population, but also play an irreplaceable role in mitigating floods and droughts, maintaining ecological balance, as well as ensuring power generation, water supply for irrigation, and navigation. In China, the global storage capacity of reservoirs is diminishing because of sedimentation with the average annual rate of storage loss being 2.3%[1], the highest in the world, and many large reservoirs in China having already passed their half-life[2].

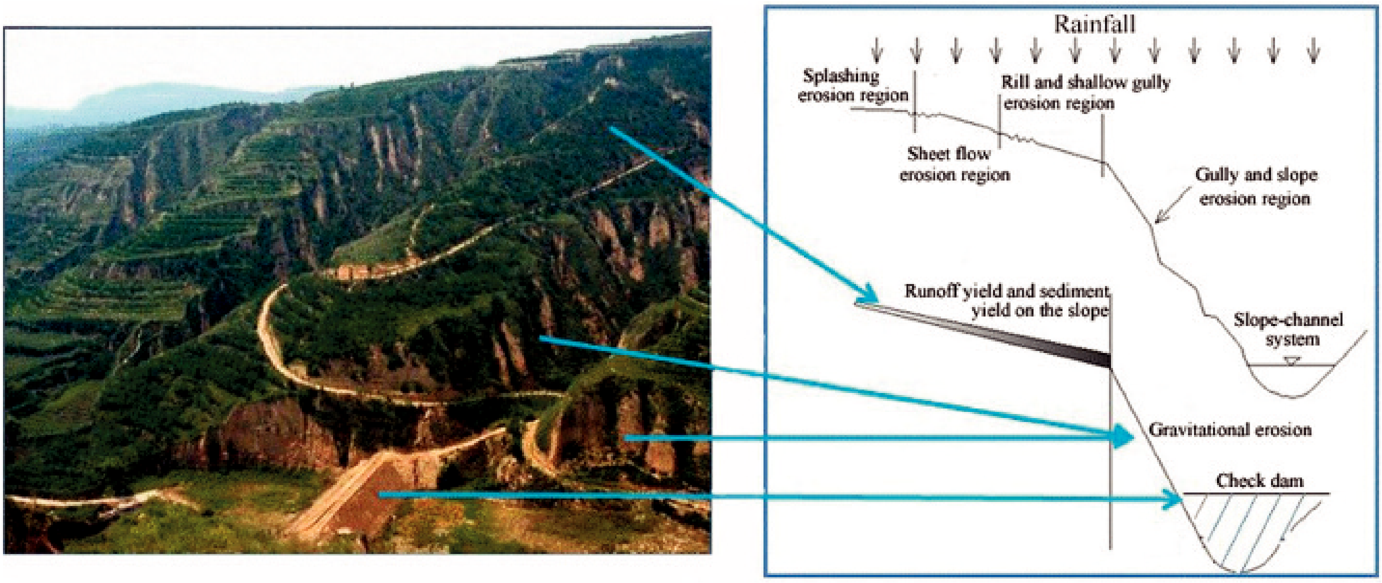
Sedimentation directly affects the benefits derived from the reservoirs, as already mentioned in several of the articles published in the two previous issues of Hydrolink on this subject. In addition, clear water released from the reservoir results in erosion of downstream river channels, which in turn gives rise to riverbank erosion and embankment/dike safety issues. Drought and flood disasters are getting more and more acute in China, exacerbated by global climate change, resulting therefore in a growing demand for long-term maintenance, sustainable use of the storage capacity of existing reservoirs and for the recovery of storage capacity loss due to sedimentation. In China, the concerned water authorities along with academia have always attached great importance to the study of reservoirs silting. They have gradually established a systematic strategy for combating reservoir sedimentation, mainly by using the following three techniques:

- reducing incoming sediment yield into reservoirs through soil and water management and conservation in watersheds;
- managing sediment within reservoirs through suitable dam operating modes (*e.g*. flushing, sluicing, turbidity venting) or bypassing part of the incoming sediment-laden waters around the reservoir to downstream reaches; and
- removing deposited sediment from reservoirs by mechanical techniques (*e.g*. dredging, dry excavation or hydrosuction).

Reducing sediment inflows

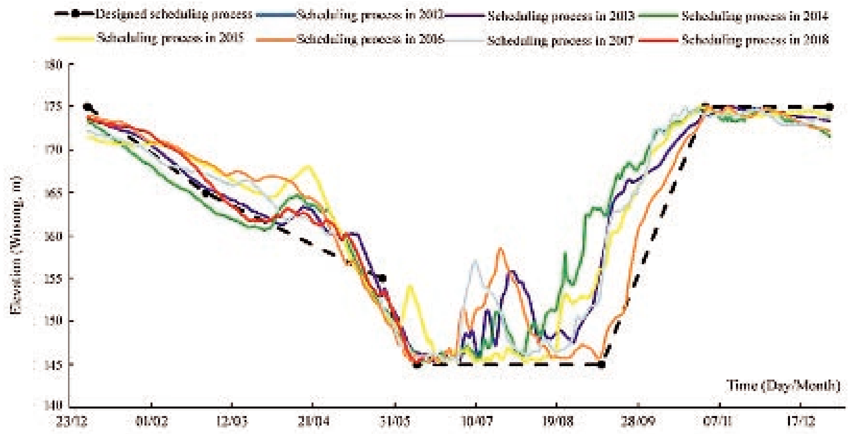
Sediment inflows into reservoirs originate from soil erosion in the watershed of the reservoir, which can ultimately be reduced through soil

Figure 1. Check dams and slope-gully system



and water management, as well as through protection and restoration of natural vegetation. China has been interested in developing integrated solutions for watershed management, treating small watersheds as individual units (dozens of square kilometers) accounting for local conditions and aiming at optimal allocation of engineering, biological and tillage measures as well as comprehensive management of the mountain, water, field, forest, road and rural environment. As the result of such strategies, soil erosion has decreased, while the utilization and productivity of land resources has improved.

Figure 2. Seasonal pool operation at the Three Gorges Reservoir



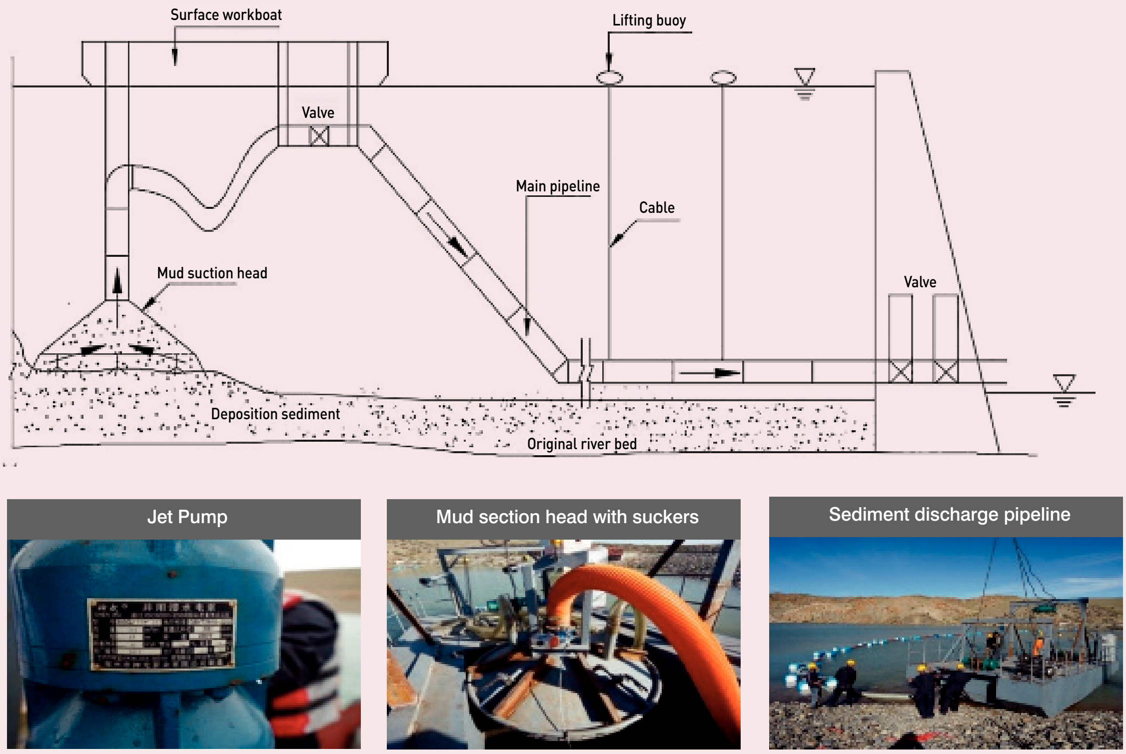
In the Loess Plateau (640,000 km^2), check dams, forest, grass vegetation and terracing are the three major measures for soil and water conservation (Figure 1). When the vegetation coverage is below 50%, the effect of increasing vegetation coverage on sediment reduction is noticeable. When the vegetation coverage exceeds 60%, the effect of further increase in vegetation cover on sediment reduction tends to be small[3]. More than 100,000 check dams have been built since 1950s in the Loess Plateau, intercepting 21 billion m^3 of sediments[4], reducing the slope of the gully channel systems to diminish their transport sediment capacity and forming fertile farmland terracing in the areas between dams. These terraced fields are basic agricultural farmlands in hilly areas, very important for improving the lives of local people. Farmland terracing changes the sloping fields into flat lands, reducing therefore the amount of soil and water losses. Leveled terraced fields not only significantly reduce their sediment yield, but also intercept sediment from the upper reaches and reduce the sediment yield in the gullies downstream by inhibiting slope runoff generation[5].

Soil and water conservation has been one of the most important mitigating strategies for reservoir sedimentation since the construction of the Sanmenxia dam in 1950s. Although it is difficult to determine the direct benefits of such strategy, it is clear that after sixty years of soil and water conservation efforts, the annual sediment load carried by the Yellow River has dropped down from 1.6 billion tons in 1950s to 0.15 billion tons since 2000, reducing therefore the sediment inflow into the Xiaolangdi reservoir as well as other small reservoirs in the Yellow river basin.

Optimizing reservoir operation modes

China's Water Conservancy science and technology staff has explored and put forward the application of the reservoir operation

Figure 3. Schematic diagram of self-suction sediment discharge piping system



Jet Pump

Mud section head with suckers

Sediment discharge pipeline

method described as “store the clear and release the muddy”, which has successfully solved the problems of sediment deposition in many reservoirs and played a very important role in achieving sustainable use of many reservoirs, such as the Xiaolangdi, Three Gorges, Xiangjiaba and Sanmenxia reservoirs. The operational mode of “store the clear and release the muddy” consists of keeping a low water level in the flood season with high sediment content to maximize flow velocity and sustain sediment transport through the reservoir (i.e. sluicing). The reservoir level is raised later in the season to ensure that only the water with lower sediment concentration be stored in the reservoir. Figure 2 shows the operation mode at the Three Gorges Reservoir, where 115 million tonnes of sediment have been retained each year since 2003[6]. According to the preliminary design, the flood control level is at elevation145 m during the annual flood season between mid of June and end of September, in which period about 90% annual sediment transported each year[6]. After the beginning of October, the reservoir water level gradually rises to reach the normal pool level at elevation 175 m to satisfy the power generation and shipping requirements. The water level is drawn down again to elevation 145 m in early June to create conditions favoring sediment flushing and sluicing. In addition, storing clear and releasing muddy depends on the reservoir, and the effectiveness of this operation depends also on the upstream runoff and sediment inflow, the gate elevation and opening, as well as the downstream discharge flow.

Figure 4. Sediment concentration in the discharge piping system at the Xiao Liu Gou reservoir

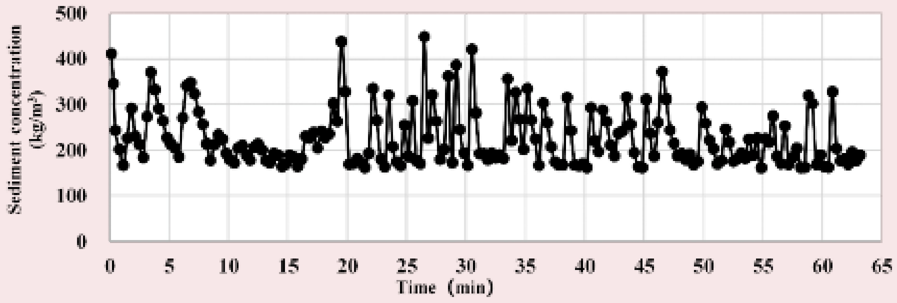
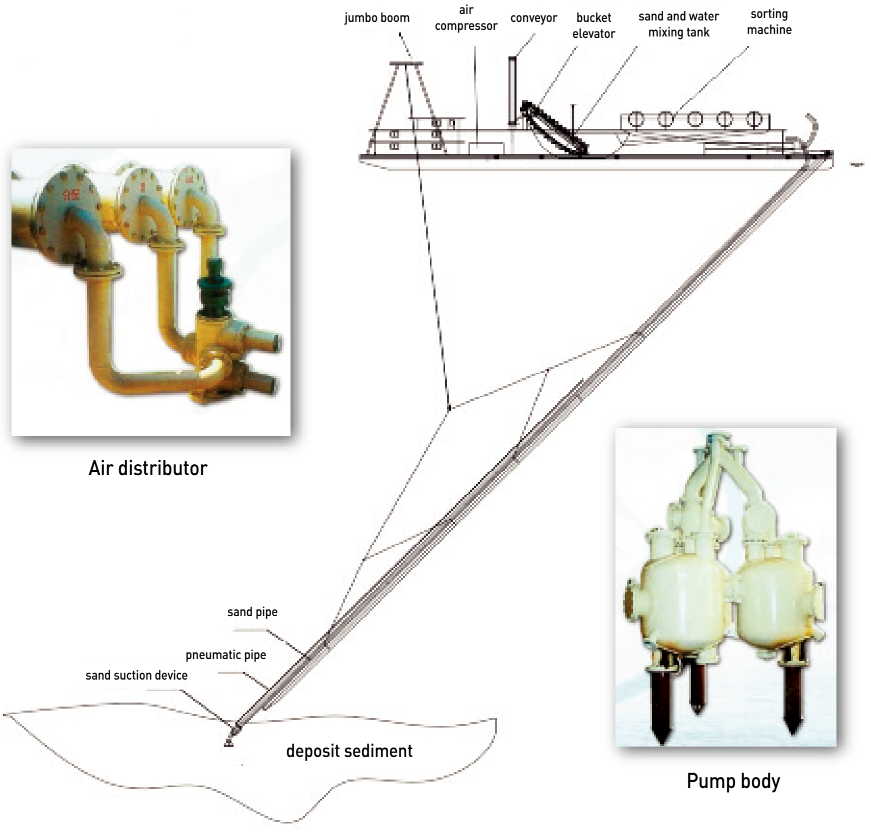


Figure 5. Pneumatic pump desilting equipment in deep water



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The strategy of storing clear water and discharging muddy flow must take into account many other factors such as flood control, water supply, power generation, shipping, ecological benefits, and the impact of the reservoir water uses on upstream and downstream . This requires continuously predicting and evaluating the effects and benefits of the actual operation mode, and exploring how to optimize the operating rules for the gates. In recent years, the specific rules for storing clear water and releasing muddy flow have been further optimized and refined[7] to meet the sustainable development of the society and the economy, under the condition that the flood risk can be well controlled and the sediment deposition within the reservoir is permitted. For example, some experimental operations and works have been carried out in the Three Gorges Reservoir, such as storing water earlier than before the end of the flood season (from mid-June to late September), controlling small and medium floods of less than 55 000 m^3s^{-1} during the flood season, silt control at the tail (upstream end) of the reservoir, and ecological operations. Since the first ecological operation of the Three Gorges Reservoir in 2011, twelve ecological operational experiments have been carried out in eight consecutive years, creating suitable flow conditions for fish spawning, promoting fish breeding in the downstream reaches.

Recovering the storage capacity

Hydraulic and mechanical desilting techniques are commonly used to remove sediment from reservoirs for recovering partially, or totally the initial storage capacity. Setting sediment discharge pipes, or self-suction sediment-piping system from the reservoir to the downstream reaches takes advantage of the head difference between upstream and downstream of the dam. A mud suction head is installed at the pipeline inlet, and the sediment is hydraulically sucked into the pipe and then discharged out of the reservoir (Figure 3). This technology needs a suction head with high capacity and efficiency for inhaling the high-density silt in the reservoir. Because of the limited working range of the suction head, it is necessary to move the head of the pipe up and down, or left to right depending on the sediment deposition conditions.

In recent years, the self-suction sediment piping technology has been improved. For instance, the Yellow River Institute of Hydraulic Research (YRIHR) carried out numerical simulations and experiments on the efficiency of suction heads. From August to October 2017, the YRIHR conducted more than 30 field desilting tests at the Xiao Liu Gou Reservoir in Hami City in the Xinjiang Uygur Autonomous Region. The equipment layout and operation mode were optimized, with the average sediment concentration outlet reaching 247 kg/m^3 in approximately 2 to 3 hours (Figure 4).

Pneumatic pump desilting technology uses high-pressure air through a special release mechanism in the pipeline, forming a strong and continuous suction force in the pipe. The Jiang Yin Water Conservancy Mechanization Engineering Company Ltd has developed a series of deep-water pneumatic pump desilting equipment, suitable for various types of coarse deposits (diameter lower than 1 m), operating at a maximum depth of 120 m with a dredging capacity of 300 m^3/h. The principal components of the pneumatic desilting system are shown in Figure 5. The compressed air is continuously released into the head of the acquisition device through the pressure-resistant pipe, and then released into the material pipe, resulting in the pressure outside the material pipe being greater than the pressure inside the pipe. Under the action of this pressure difference, sediments near the mouth of the material pipe are sucked and transported to surface ships or pipelines. Four material pipe diameters are available, 0.20 m, 0.35 m, 0.60 m and 1 m. The pneumatic pump desilting technology has been successfully applied in many sites in China, including the Zhentouba Reservoir in the Dadu River, the Jinping-II hydropower station in the Yalong River (Figure 6) and the Longkou reservoir in the Yellow River (Figure 7).

Acknowledgements

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Figure 6. Jinping-II hydropower station in the Yalong Rive - Dredging operation showing the barge and removed material

Figure 7. Dredging project of the tailrace canal of the Longkou reservoir in the Yellow River. The material diameter was 1 m.

References

[1] Jiang, N., Fu, L. (1998). Problems of reservoir sedimentation in China. Chinese Geographical Science, 8(02): 22–30.
[2] Wang, Z.-Y., Hu, C. (2009). Strategies for managing reservoir sedimentation. International Journal of Sediment Research, 24(4): 369–384.
[3] Zhang, X., Cao, W. Guo, W., Wu, S. (2010). Effects of land use changes on surface runoff and sediment yield at different watershed scales on the Loess Plateau. International Journal of Sediment Research, 25(3): 283–293.
[4] Jin, Z., Cui, B., Song, Y., Shi, W., Wang, K., Wang, Y. (2012). How many check dams do we need to build on the Loess Plateau? Environmental Science and Technology 46: 8527–8528.
[5] Liu, X., Wang, F., Yang, S. (2014). Sediment reduction effect of level terrace in the hilly-gully region in the Loess Plateau. *IWHR* Journal of Hydraulic Engineering, 2014, 45(7): 793–800. (In Chinese)
[6] Huang, R., Wang, M., Zhang, X., Liu, L., Ren, S., Zhou, M. (2018). Preliminary study on dynamic operation mode of “Storing clear water and releasing muddy water” in the Three Gorges Reservoir in flood season. Journal of Yangtze River Scientific Research Institute, 35(7): 9–13. (In Chinese)
[7] Hu, C. (2016). Development and practice of the operation mode of “Storing clear water and discharging muddy flow” in sediment-laden rivers in China. *IWHR* Journal of Hydraulic Engineering, 47(3): 283–291. (In Chinese)