Journal of Hydrology 528 (2015) 230–237

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Artificial tide generation and its effects on the water environment in the backwater of Three Gorges Reservoir

Yukun Sha [a,b,d], Yongping Wei [c], Weipeng Li [a,b], Jihui Fan [a,b], Genwei Cheng [a,b,*]

[a] Institute of Mountain Hazard and Environment, CAS, Chengdu 610041, China
[b] Key Laboratory of Mountain Surface Process and Ecological Regulation, CAS, Chengdu 610041, China
[c] Australian-China Centre on Water Resources Research, University of Melbourne, Parkville 3010, Australia
[d] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form 7 May 2015
Accepted 11 June 2015
Available online 23 June 2015
This manuscript was handled by Laurent Charlet, Editor-in-Chief, with the assistance of Fereidoun Rezanezhad, Associate Editor

Keywords:
Three Gorges Reservoir
Water bloom control
Hydropower daily operation
Artificial tide generation

SUMMARY

Since the water impounding of the Three Gorges Reservoir (TGR) in 2003, the water stage in the backwater region increased from 65 m before water impounding to 145 m, and the velocity of the stream flow decreased significantly. The outflows of the tributaries that flow into TGR were also obstructed by the backwater. Stopping the stream flow prevented the pollutants from diffusing and transporting themselves into the water body, hence polluting the water in several tributaries. The authors proposed an artificial tide generation approach to solve this problem. The man-made flood peak in the downstream and the waves of the water stage in the upstream of the TGR can be produced by operating hydropower generators daily to deal with peak-and-bottom variations in the electricity demand. These waves will propagate upwards and form artificial tides in the backwater area. The water stage variation will intensify the flow exchange between the main stem and the tributaries as well as enhance the diffusion of pollutants, which will subsequently decrease the eutrophication of the water body in the outlet of branches as well as relieve the algal bloom problem in the region. The daily operations in the reservoir were simulated and tested by using the proposed hydrodynamic model of TGR. The hydropower operation for the peak load of electricity demand will produce artificial tides in the backwater area of TGR as well as increase the water stage variation from 0.30 m to 0.50 m within a day. This periodic fluctuation of water stage waves will intensify the water exchange between the main reach of Changjiang (Yangtze River) and its tributaries with an additional inflow or outflow of up to 300–500 m^3/s, which is equivalent to the average discharge of these tributaries during the summer. The artificial tide generation can enhance the internal exchange of backwater as well as improve the water environment condition in the backwater area. This operation approach provides a new technology for controlling the water quality in reservoirs as well as enhances environmental protection and resource utility.

1. Introduction

Since its water impoundment in 2003, the Three Gorges Reservoir (TGR) had been in operation and greatly contributed to flood control, navigation, and electricity generation. However, after the water stage exceeded the designed levels of 145 m (during the flood season or summer) and 175 m (during the low-flow season or winter), the backwater became a man-made lake with a steady water surface. The N and P elements from the upstream were concentrated in this area, and eutrophication of the water body became a key problem that led to the emergence of algal blooms in the outlet of the tributaries in the backwater of TGR. The degradation of water quality might harm the communities of this region and affect the normal operation of the reservoir. The water in TGR is being polluted by the high loading discharge of wastewater from cities and industries that operate in the upper Changjiang (Yangtze River) valley. The wastewater flows through the tributaries and are concentrated in the backwater. The low flow velocity in the backwater is also an important factor that contributes to the water pollution. After the water impoundment of TGR, the water stage in the backwater of the reservoir demonstrated small variations that blocked and nearly stopped the stream flows of the tributaries. These incidents also promoted the sudden, frequent emergence of algal blooms in the area.

* Corresponding author at: Institute of Mountain Hazard and Environment, Chinese Academy of Sciences, No. 9, Block 4, Renmingnan Road, Chengdu 610041, China. Mobile: +86 13981862737.

E-mail address: gwcheng@imde.ac.cn (G. Cheng).

http://dx.doi.org/10.1016/j.jhydrol.2015.06.020
0022-1694/

The three gorges of the upper Yangtze River form the valley that begins from Cuntan of Congqing City and ends at Yichang City, covering a total area of 55,100 km^2. This region includes 40 tributaries with a watershed area that is larger than 100 km^2. Before the water impoundment of TGR, the flow velocities of the tributaries ranged approximately from 0.5 m/s to 1.0 m/s. Higher velocities increased suspended sediment concentrations. A higher flow velocity and sediment content reduced the transparency of the water in the reservoir, which had a visible depth of 0.50–0.70 m. Given that mobile and dim water environments confined algae growth, few algae blooms were recorded in this area before 2003. After the water impounding of TGR, the water stage began to exceed 40 m, the outlet of the tributaries were blocked by the backwater, the flow velocity was reduced to the range of 0.02–0.05 m/s, and the visible depth of the water was increased to 2 m. The lake-like condition provided a favorable environment for algae reproduction. The main tributaries in the TGP region, such as Xiangxi River, Meixi River, Shengnongxi River, Daninghe River, and Xiaojing River, suffer from a breakout of algal blooms several times in a year. The bloom areas were spread 4–8 km from the outlet of the tributary. The algae content in these areas increased from 1.0×10^6 to 1.5×10^8 cell/L, and the Chl-a content ranged between 1500 and 3000 μg/L, which was much higher than the serious bloom grade(Qi, 2003; Zhang et al., 2007).

Eutrophication is one of the most serious ecological problems in the aquatic ecosystem and usually takes place in lakes, reservoirs, and estuaries (Nezlin et al., 2009; Luo et al., 2011). This phenomenon is commonly considered a major contributor to global environmental degradation (Nixon, 1995; Wang et al., 2010). TGR, which is the largest hydropower complex project in the world, is located in the middle reach of Yangtze River in China (Wu et al., 2003; Shen and Xie, 2004; Müller et al., 2008). The flow velocity in some tributaries in the reservoir became very slow (some were below 0.05 m/s) after the impounding of TGR (Li et al., 2006; Yang et al., 2010). Such a slow flow velocity can weaken water exchange in the vertical direction as well as lead to the deposition of nutrients and silt materials. As a result, the phytoplankton may grow quickly. Algae blooms were frequently observed in the backwater area during spring and autumn over the recent years (Yan et al., 2008; Wang et al., 2009, 2010). The eutrophication in the TGR bays became a major environmental problem that attracted increasing attention from other parts of the world.

The emergence of algae blooms can be controlled through physical, chemical, and biological measurements (Qin et al., 2006; Yang et al., 2010). An important aspect of the high variability of the tidal water area is related to the short-time effects of a tidal cycle on the physicochemical characteristics and biological conditions of the water (Montani et al., 1998; Chauhan et al., 2009). The rise and ebb of the water surface during flood tides dramatically influence the master variables of the water column, such as suspended particulate matter and redox potential, as well as the abundance of planktons (Dale and Prego, 2003; Youn and Choi, 2008; Gao et al., 2008). The extent of such variations will vary greatly depending on the spring and neap tide state or the tidal amplitude (Uncles and Stephens, 1996; Hatje, 2003). For example, the distribution and abundance of different groups of planktons not only follow the tidal rhythm, but also depend on the strength of the current and the direction of the water flow (Mohan and Rao, 1971; Goulder, 1976; Roden, 1994). Therefore, tides can dissipate the contaminants through passive and active water movements as well as affect ambient nutrient concentrations and water quality (Mohandass et al., 2010). Understanding the influence of tides is critical to both the basic ecology of the tidal water area and the mitigation of pollutants in lakes or rivers.

After the TGR project was completed in 2006, an electric power output of 2.70–13.10 million kW was produced everyday even during low flow seasons (winter), which corresponded to the variation of the downstream discharge from the TGR dam (from 2800 m^3/s to 14,500 m^3/s) (Zhou, 2005). The electricity generation and downstream discharge of the TGR power station demonstrated relatively stable periodic variations assuming that the power system load was regulated every day and night. This periodic variation could produce a wide range of fixed-cycle water stage fluctuations in the backwater. This water wave is similar to a tidal variation and may turn tributaries into "tidal rivers." The artificial tide can induce a strong water exchange between the tributaries and the main stem, increase the flow velocity, and enhance the mixing effects. The objective was to discuss the environmental issues in the backwater of TGR and its tributaries as well as explore the possibility of controlling pollution in the backwater region by

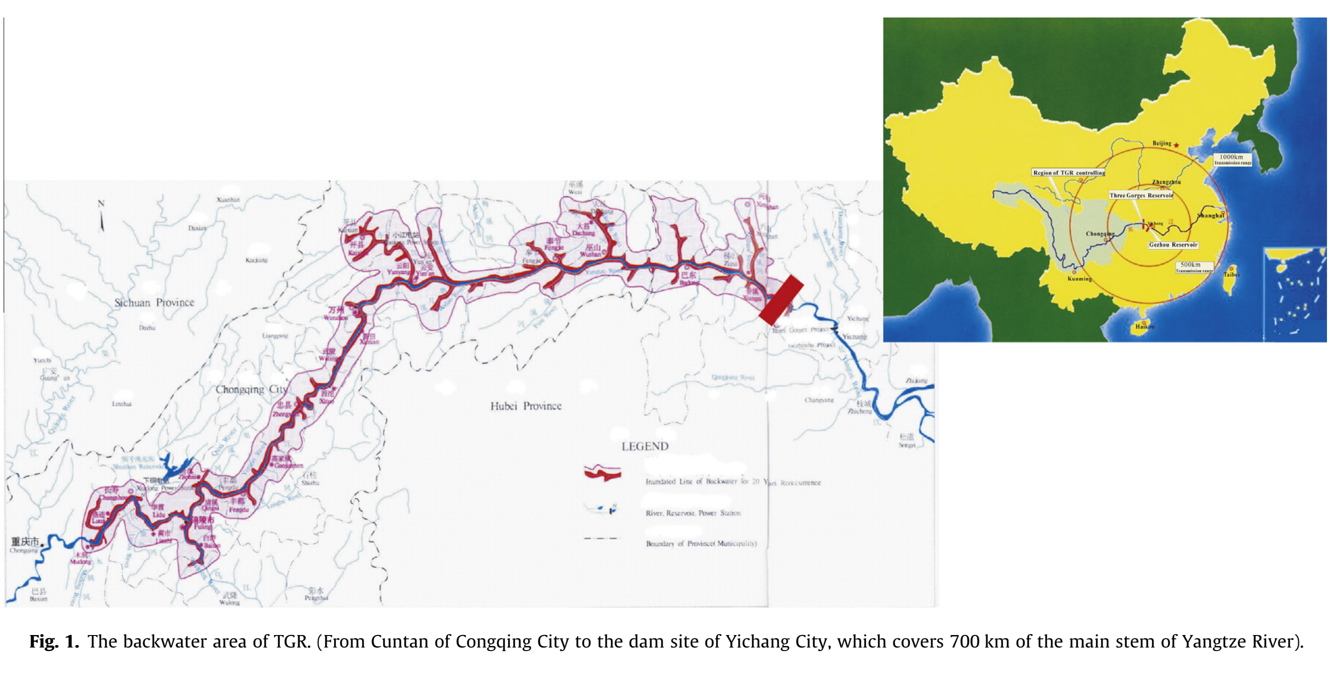

Fig. 1. The backwater area of TGR. (From Cuntan of Congqing City to the dam site of Yichang City, which covers 700 km of the main stem of Yangtze River).