

RESERVOIR OPERATION RULES FOR CONTROLLING ALGAL BLOOMS IN A TRIBUTARY TO THE IMPOUNDMENT OF THREE GORGES DAM

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Since the first impoundment of Three Gorges Dam in 2003, algal blooms occur frequently in the near-dam tributaries. An attempt is made in our study to develop reservoir operation rules that would reduce the level of algal blooms in the near-dam tributaries. The reservoir operations can further increase the water exchange between the mainstream of the Three Gorges Reservoir and the Xiangxi River tributary and thus move a larger amount of algae into the deep water where it would die. Analysis of the model results indicated that water discharge fluctuations consisting of a lower night-time valley-load flow and a larger flow component to satisfy daytime peak load during short-term operations (within a day), the rise in water level during the medium-term operation (e.g., over weeks), and the combination of these two during the long-term operation (e.g., over months) can provide feasible reservoir operation rules in the non-flood season for TGR.

What is the problem?

After reservoir impoundment, the hydrodynamic conditions significantly changed from those occurring under the natural state of the river. Lower water velocity and longer residence time, resulted in degraded water quality and eutrophication problems^[1,2]. The Three Gorges Reservoir (TGR) is the largest man-made reservoir system in the world according to the annual report of eco-environmental monitoring of TGR released by Executive Office of the State Council Three Gorges Project Construction Committee^[3]. More than 30% of the monitoring sections in the major tributaries are in a state of high eutrophication, and algal blooms occur in over 20 tributaries from March to October every year, such as the Xiangxi River (XXR), the Tongzhuang River and the Daning River. Algal blooms occurring in XXR seriously affect the quality of life of local residents because of increased water turbidity and odor problems^[4,5]. Harmful algal blooms with toxins are a prime agent of water quality degradation and result in loss of water for recreation and drinking. In order to alleviate the increasing algal bloom problems in TGR, more and more attention is being paid to seeking feasible solutions.

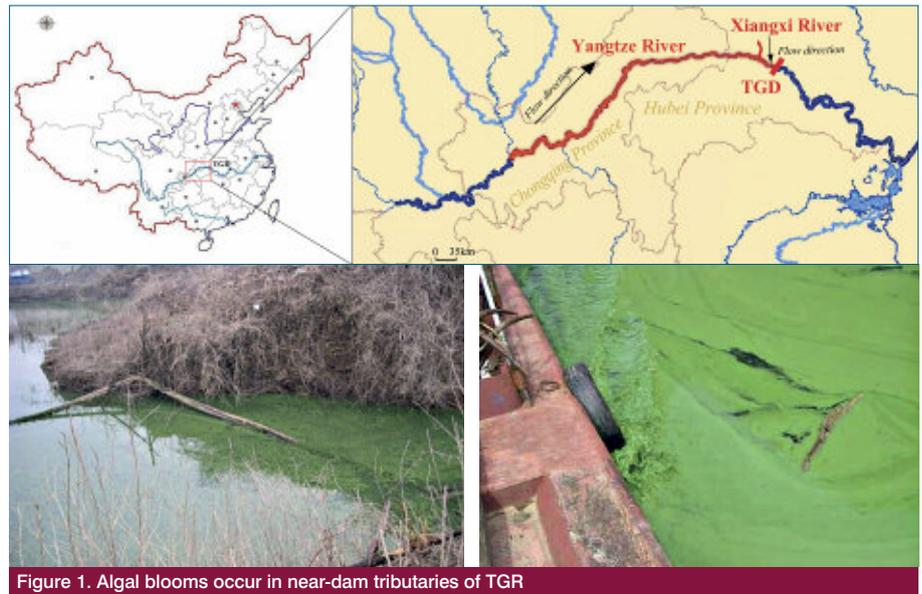


Figure 1. Algal blooms occur in near-dam tributaries of TGR

How did the reservoir operation rules come?

The occurrence of algal blooms in near-dam tributaries of TGR in the studied non-flood season is caused by slow water movement, which in combination with favorable meteorological conditions (e.g., warm air, low wind) and high nutrient loads, provides suitable environment for algae to grow. Xiangxi River (XXR), a near-dam tributary of TGR, is used as an example, in an attempt to develop reservoir operation rules that would reduce the level of algal blooms. For this purpose, a hydrodynamic and water quality model for the mainstream of TGR and the XXR arm (TGR-XXR model) was developed and calibrated using the CE-QUAL-W2 software to study the influence of reservoir operations on the algal blooms.

The formulation of reservoir operation rules is based on the current scheduling rules of the Three Gorges Hydropower Station as well as on scenario simulations. Water movement and algal bloom processes in XXR are simulated and analyzed under different scenarios of short-term daily water discharge fluctuations or medium-term water level variations using chlorophyll-a as the indicator for algal blooms.

The daily water discharge process is planned according to the daily inflow, the release requirements and load demand with peak-load regulation. The day is divided into four typical periods and four transition periods with a total of 48 time intervals (each being 0.5 hours), including the valley-load period (when the discharge is the lowest) (0:00–6:00), the morning peak-load period (8:00–11:00), the medium-load period (12:00–17:00), and the evening peak-load period (19:00–22:00). The water discharge does not change over each of the previously defined load periods but it changes linearly during each transition period. The flow difference is the difference between the water discharge in the evening peak-load period (peak-load flow) and the valley-load period (valley-load flow). Different scenarios include different combinations of valley-load flow and flow difference. For the medium-term operation, the water level variation over a period of time is set to rise or fall

How do the reservoir operation influence algal blooms?

During the season when algal blooms occur frequently, water from the mainstream TGR enters into the upper layers of the XXR arm of

the reservoir and outflow from the XXR arm discharges from its lower layers into the main TGR as a result of the water temperature difference between the two river branches. Contour plots of Chl-a concentration on four different Julian days, from the beginning to the end day of the 40-day simulation period, are shown in Figure 2. The vertical distribution of velocity vectors at various locations along the longitudinal direction are also shown in the same figure. The velocity vectors illustrate the flow field described above and also help understand how algae move through the reservoir. (It is noted that the distance shown on the horizontal axis in Figure 2 is from the upstream to the downstream end of the reservoir.) Algae primarily grow in the upper layers and emerge at the water surface, so they are mainly influenced by the flows in a direction from downstream to upstream within XXR, which come from the mainstream TGR. The flow from the downstream to the upstream pushes the algae towards the upstream end of the XXR arm of the reservoir, and the concentration of algae at the confluence with the mainstream TGR is diluted since the Chl-a concentration in the mainstream of TGR is always lower than that in the XXR [2]. When the algae reach the upstream boundary of the backwater zone created by the impoundment of TGR, they are carried by the flow downwards into the deep water where the conditions of no light and lower temperatures are not suitable for their growth. There the algae die gradually. Thus, the transport process of algae in the XXR arm of the reservoir is characterized by a counterclockwise motion.

The reservoir operation is used to accelerate the transport process of algae by enhancing the

water exchange between the two river branches, in order to reduce the algal bloom level. Flow fluctuations through the peak-load regulation provide an effective way of strengthening the water exchange between the mainstream reservoir and the tributary arm, because peak-load regulation makes both the flow entering from the mainstream into the XXR arm of the reservoir and the discharge flow from the XXR arm into the mainstream reservoir large. More intensive flow pushes the algae towards the upstream end of the XXR arm and moves them into deep water faster. In the meantime, the water level rise, similar to the peak-load regulation is also effective for reducing the algal bloom level by strengthening the flow into XXR to accelerate the upstream transport process of algae.

Reservoir Operation Rules for Controlling Algal Blooms

In conclusion, the reservoir operation can contribute to water quality improvement in the XXR as it can enhance the water exchange between the mainstream of TGR and the XXR tributary resulting in more water from the mainstream entering into the XXR leading to higher dilution, as well as in the acceleration of the transport of algae. Through the comparisons of algal bloom levels under different values of operation factors, operation rules aimed at water quality improvement are formulated. For short-term operation, daily peak-load regulation should be conducted. For the medium-term operation, regulation over a period of two weeks for water level rise can be conducted. For TGR, if inflows are sufficient, the water level can be raised to a certain extent in non-flood season without influencing the reservoir flood control



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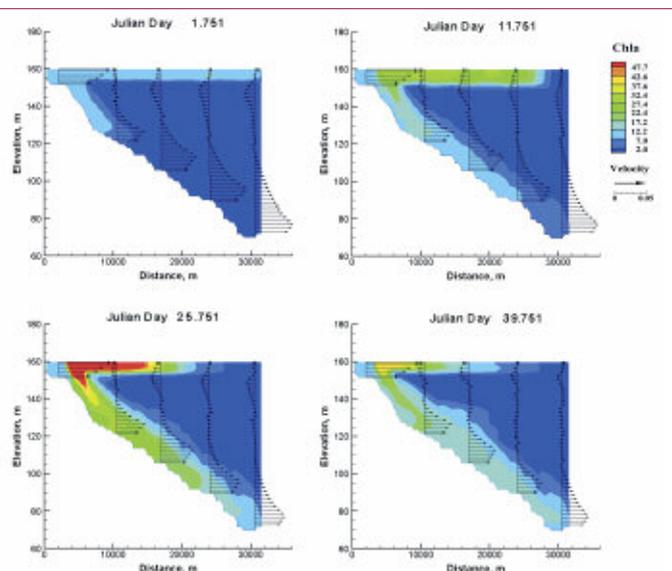
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Figure 2. Transport process for algae in XXR under one scenario



capacity. Thus water level rise is beneficial for both algal blooms control and electricity generation. For long-term operation (e.g., over months) in the non-flood season for TGR, the short-term flow regulation and medium-term water level rise can be combined periodically. ■

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