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Study of the application of the water-lifting aerators to improve the water quality of a stratified, eutrophicated reservoir

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ABSTRACT

Cyanobacterial blooms accompanied by a release of nutrients from the bottom sediments in the stratified summer period continue to be a serious nuisance to water quality managers. Water-lifting and aeration technology can be used to inhibit algal growth while controlling internal pollutants. In this study, two water-lifting aerators (WLAs) were installed in a stratified, eutrophicated reservoir to investigate its ability to improve the water quality. The results showed that the lower water layer was directly oxygenated by WLAs. After the WLAs operated for a month, the concentration of dissolved oxygen at the bottom increased from 0 mg/L to 5 mg/L; the release of internal pollutants had effectively been suppressed. The advection generated by the circulated flow from WLAs can transport algae from the surface layer to the bottom layer. The mixing function of WLAs can control algal growth, and its mixed conduction speed gradient can effectively resist cyanobacteria floatation and reduce the competitive advantage of harmful algae, which changes the quantity and structure of the phytoplankton community. The algal cell density decreased to less than 10 million/L, with cyanobacteria accounting for only 16% of the population in the area of 10 m away from the WLA. The quantity of algae reached to 100 million/L and included Microcystis, which accounted for 91% of the population in the area of 100 m away from the WLA after three weeks of operation. The results can provide direct technical support for reservoir restoration.

1. Introduction

Thermal stratification plays an important role in the dynamics of water quality and the ecological characteristics of lakes and reservoirs (Elçi, 2008; Han et al., 2000; Rangel-Peraza et al., 2012; Wang et al., 2014). The hypolimnion becomes anoxic during the stratified period, which increases the release of pollutants from the bottom sediments and leads to the periodic deterioration of water quality (Beutel et al., 2008; Jankowski et al., 2006). Some studies of the water quality of subtropical and tropical reservoirs have found that thermal stratification can lead to anoxic conditions in the hypolimnion throughout most of the year (Hawley et al., 2006; Wang et al., 2012). Longer periods of anoxia result in the more significant deterioration of water quality as reduced species continue to diffuse out of the sediment and enter the hypolimnion. Two major countermeasures are available for the anoxic condition in the lower water layer due to stratification: one strategy overcomes water stratification using artificial mixing techniques. The other aims to directly oxygenate the water in the deep layer with hypolimnetic oxygenation systems (Antenucci et al., 2005; Bryant et al., 2011; Chowdhury et al., 2014; Soltero et al., 1994). Even though de-stratification can improve the dissolved oxygen content in the hypolimnion by mixing it oxygen-enriched surface water, hypolimnetic oxygenation is more widely applied to mitigate anoxia in the hypolimnion. This strategy retains natural stratification in order to preserve the habitat for the fauna living in the cold waters at the bottom, avoid the pollutant release that ensues from mixing the bottom sediment mixed with the surface water and reduce the operation cost (Beutel, 2006; Bryant et al., 2011; Gantzer et al., 2009; Toffolon et al., 2012).

Reservoirs have created an artificial environment conducive to algal growth, with calm waters, low light attenuation and a relatively long residence time. Toxic cyanobacterial blooms in reservoirs have become a worldwide problem (Costa et al., 2006; O'Neil et al., 2012Tarczyska et al., 2001; Te and Gin, 2011). Although any resources that are essential for algae growth can be potentially limited, available nutrient (in particular C, N, P, and Si for diatoms) and light primarily drive the change of the phytoplankton communities (Chen et al., 2009; Paerl et al., 2011a, 2011b, 2011c). Summer stratification generally favors potentially toxic cyanobacterial biomass due to their higher affinity for nutrients compared to other phytoplankton species and their ability to

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adjust their buoyancy and therefore exploit nutrients, light and inorganic carbon resources over a wider range (Liu et al., 2012; Wynne et al., 2008). A number of ecological engineering techniques have been used to control cyanobacteria blooms, such as altering the hydrology to enhance vertical mixing and flushing to counter the formation of cyanobacteria surface blooms (Li et al., 2013; Lundgren et al., 2013; Thackeray et al., 2006), the operation of a bypass to decrease nutrient loads and the transportation of phytoplankton from upstream areas to the reservoir (Yajima et al., 2013), and bio-manipulation by means of introducing fish to increase the grazing pressure on cyanobacteria. Unfortunately, application of these techniques in other reservoirs has several limitations; meanwhile, the reservoir management department also wants to use more effective technique to control cyanobacterial bloom in situ (Upadhyay et al., 2013).

Cyanobacterial blooms accompanied by the release of nutrients from the bottom sediments during the stratified summer period have become a common problem for most eutrophic, stratified reservoirs; these blooms seriously threaten drinking water supplies and ecological sustainability. Although the ability of artificial mixing techniques to solve the above problems has been widely confirmed, few comprehensive studies of the effects of the practical application and operating conditions of technologies to inhibit cyanobacterial blooms and the release of internal pollutants have been published, especially in China (Kim et al., 2007; Yum et al., 2008). In this research, two water-lifting aerators (WLAs) made of fiber reinforced polypropylene (FRPP) were installed in a stratified eutrophicated reservoir to improve the water quality. The WLA is a new type of artificial mixing equipment that has two major functions: mixing the lower and the upper water layers and directly oxygenating the lower water layer (Cong et al., 2010, 2011, 2009). We aimed to investigate the mixing and oxygenation capacity of this technique for controlling the algae bloom and the release of internal pollutants as well as the broader impacts on reservoir water quality.

2. Material and methods

2.1. Study site

The Shibianyu Reservoir (SBYR) is a medium-sized canyon-shaped reservoir located in a warm temperate zone approximately 35 km southwest of Xi'an city in Shaanxi province, northwest of China (Fig. 1). It was built in 1975, began to supply water to Xi'an starting in August 1990, and was used for flood control, agricultural irrigation, and power generation. The total capacity of the SBYR is 28.1 million m^3, and it supplies 30 million m^3 water to Xi'an every year. Generally, the high water level is 731 m above sea level (a.s.l.), and the low water level is 675 m a.s.l. As the city backup water resource, the water quality of the SBYR plays an important role in ensuring urban water security.

Originating from the Qinling Mountain, Shibianyu River is the main stream to supply the SBYR in Shaanxi Province (Fig. 1). This river is 30 km long with a catchment area of 132 km^2; the annual

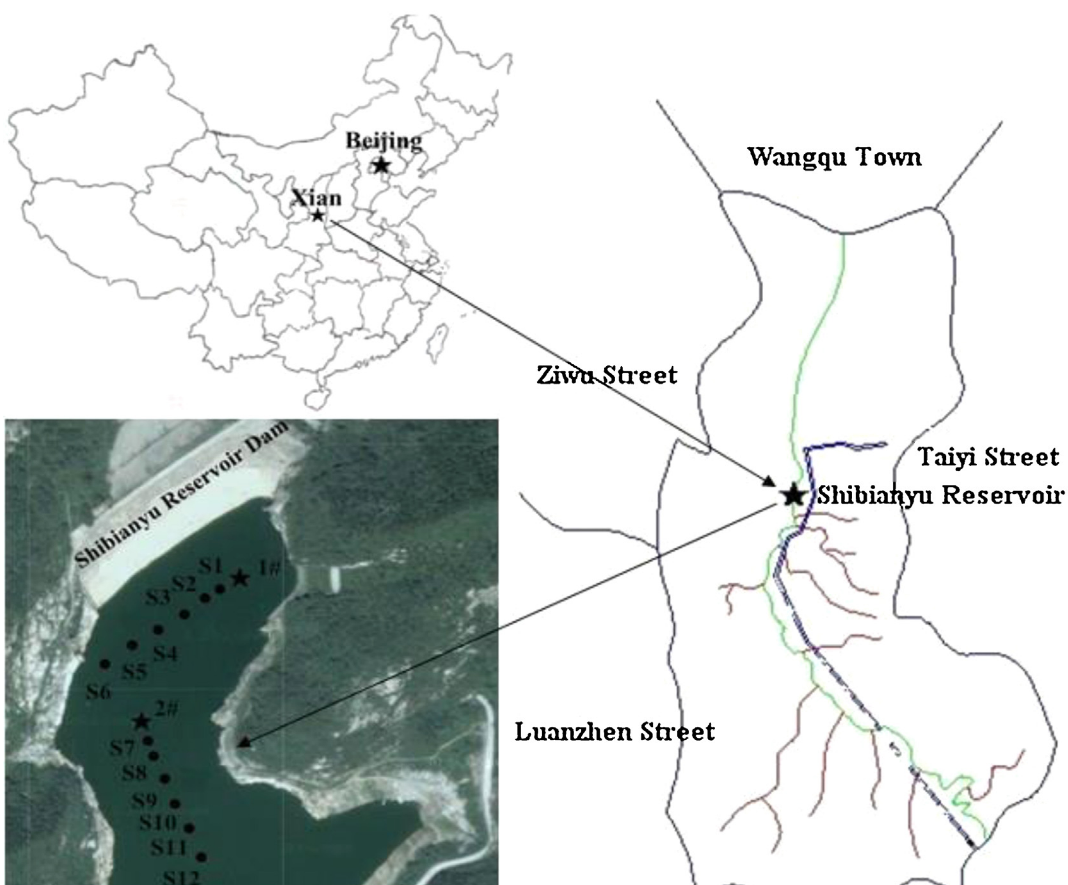

Fig. 1. Illustration of Shibianyu reservoir showing the location of the water-lifting aerators and the monitoring sites.