JOURNAL OF ENVIRONMENTAL SCIENCES XX (2016) XXX–XXX

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JES JOURNAL OF ENVIRONMENTAL SCIENCES www.jesc.ac.cn

Sediment pollution characteristics and *in situ* control in a deep drinking water reservoir

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ARTICLE INFO

Article history:
Received 26 January 2016
Revised 9 May 2016
Accepted 11 May 2016
Available online xxxx

Keywords:
Sediment pollution
In situ reactor
Water-lifting aerator
Sediment release inhibition

ABSTRACT

Sediment pollution characteristics, *in situ* sediment release potential, and *in situ* inhibition of sediment release were investigated in a drinking water reservoir. Results showed that organic carbon (OC), total nitrogen (TN), and total phosphorus (TP) in sediments increased from the reservoir mouth to the main reservoir. Fraction analysis indicated that nitrogen in ion exchangeable form and NaOH-extractable P (Fe/Al-P) accounted for 43% and 26% of TN and TP in sediments of the main reservoir. The Risk Assessment Code for metal elements showed that Fe and Mn posed high to very high risk. The results of the *in situ* reactor experiment in the main reservoir showed the same trends as those observed in the natural state of the reservoir in 2011 and 2012; the maximum concentrations of total OC, TN, TP, Fe, and Mn reached 4.42 mg/L, 3.33 mg/L, 0.22 mg/L, 2.56 mg/L, and 0.61 mg/L, respectively. An *in situ* sediment release inhibition technology, the water-lifting aerator, was utilized in the reservoir. The results of operating the water-lifting aerator indicated that sediment release was successfully inhibited and that OC, TN, TP, Fe, and Mn in surface sediment could be reduced by 13.25%, 15.23%, 14.10%, 5.32%, and 3.94%, respectively.

Introduction

Various pollutants adsorb to sediments that accumulate at the bottom of reservoirs. These sediments accumulate over long periods of time and can act as new pollutant sources to the overlying water (Sun et al., 2009; Młynarczyk et al., 2013). The forms and types of pollutants usually vary in different sediments because bonding forces vary with respect to grain size (Ruttenberg, 1992; Bo et al., 2003), which results in different release times and release potentials.

As is well known, nitrogen and phosphorus are the most common macronutrients for phytoplankton growth. Furthermore, the nitrogen and phosphorus transport processes between sediments and overlying water play a crucial role in the aquatic ecological environment (Huang et al., 2015). Meanwhile, heavy metal pollution is an environmental crisis that accompanies rapid economic development in many countries. Metal elements constitute an environmental threat by creating serious human health hazards and affecting ecological food chains (Souza and Wasserman, 2015; Xuelu and Chen-Tung Arthur, 2012). To clarify the transport processes, first we should have a clear understanding of the nitrogen, phosphorus, and metal element fractions and release potentials in sediments. During the stratification period, sediment release in Grand Lake (Nikolai et al., 2014) yielded total nitrogen (TN) and total phosphorus (TP) concentrations in the hypolimnion of 1.1 mg/L and 0.17 mg/L, respectively. Soluble Fe and Mn also reached problematic

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http://dx.doi.org/10.1016/j.jes.2016.05.006
1001-0742 © 2016 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V.

levels during the summer stratification in Carvins Cove Reservoir (Nikolai et al., 2014). Thus, sediments act as a source of pollution.

Many laboratory studies have reported on sediment release of N, P, Fe, and Mn (Wang et al., 2014; Wu and Hua, 2014; Zhang et al., 2014). Considering the sediment form changes as well as pressure and temperature variations that occur in real settings, laboratory release experiments are not a reliable reflection of sediment release in reservoirs. In the present study, a new *in situ* reactor was used to study the release characteristics of pollutants in a canyon-shaped deep-water reservoir. Using the intact sediment and true pressure, the *in situ* reactor was used to produce more credible data. Of the *in situ* sediment remediation strategies, sediment capping has been applied in Lake Taihu (Xu et al., 2012) for internal P control, but this method could not be applied in the Jinpen Reservoir for deposition carried by runoff. Additives that were used in Suzhou Creek (Qian et al., 2009) successfully stabilized the metal elements, but this may also cause new problems in drinking water reservoirs, such as increased iron from additives containing ferrihydrite. Dredging for sediment remediation is always toxic to phytoplankton and autotrophic bacteria (Nayar et al., 2004). In this study, sediment release control using water-lifting aerators (WLAs) was shown to be clean and environmentally safe. We also demonstrated significant results: concentrations of organic carbon (OC), TN, TP, Fe, and Mn in the sediment were reduced during the operation of WLAs. The goal of this study was to understand the pollution status and release potential of reservoir sediments and to improve the ability of WLAs to control the release of internal sediments.

1. Materials and methods

1.1. Sampling sites

Jinpen Reservoir (34°42′ 0–34°13′N; 107°43′–108°24′E) is the main drinking water reservoir of Xi'an City in Shaanxi Province, China. Jinpen Reservoir is located at the foot of the Qinling Mountains, 90 km from Xi'an City, as shown in Fig. 1. It is a canyon-shaped deep-water reservoir, and the main reservoir length extends 3.5 km. The total capacity of the reservoir is 2.0×10^8 m^3. When full, the surface area of the reservoir is 4.55 km^2. The main function of the reservoir is urban water supply; agricultural irrigation, power generation, and flood control are accessory functions.

The Heihe River, which originates in the Qinling Mountains, is the main water supply for Jinpen Reservoir. The river is 91.2 km long with a catchment area of 1418 km^2, and the catchment is largely undeveloped and consists primarily of forested mountains. Along the reservoir, six representative sampling sites were chosen. S1 (33°58′26.91″E, 108°08′50.02″N, depth 1 m) was located at the reservoir mouth; S2 (34°00′16.7″E, 108°10′38.67″N, depth 5 m) and S3 (34°01′14.24″E, 108°10′58.1″N, depth 20 m) were upstream from the reservoir; S4 (34°01′58.17″E, 108°11′13.78″N, depth 40 m) was near the middle of the reservoir; S5 (34°02′35.95″E, 108°11′52.83″N , depth 65 m) and S6 (34°02′ 42.20″E 108°12′22.76″N 70, depth 70 m) represented the main reservoir.

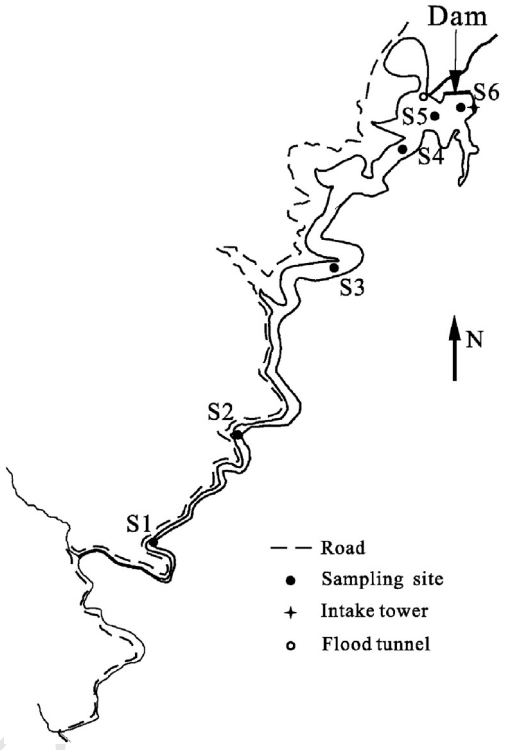

Fig. 1 – Position of Jinpen Reservoir and sampling sites (S1–S6).

1.2. Field work

Sediment samples were collected using a core sampler (HL-CN, Hengling technology Ltd., Corp., China; Ni and Wang, 2015). Sediment columns that showed no evidence of disturbance were retained. One centimeter segments of the sediment columns were collected, transferred to pre-cleaned polythene bags, and sealed. Sediment samples were kept at −4°C until laboratory processing (Zahra et al., 2013).

The *in situ* reactor utilized is a proprietary device specially designed for the investigation of migration and transformation of substances at the sediment–water interface, and its schematic diagram is shown in Fig. 2. The reactor is a stainless steel cylinder with its bottom open. The *in situ* reactor was installed at the water–sediment interface using a windlass with a wire rope, and the lower part of the reactor was embedded into the sediment by its own weight. The water in the reactor was separated from the surrounding water, and dissolved oxygen (DO) consumption and sediment Q4

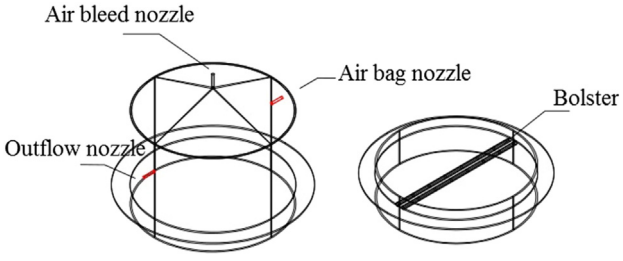

Fig. 2 – Schematic diagram of the *in situ* reactor.

Please cite this article as: Zhou, Z., et al., Sediment pollution characteristics and *in situ* control in a deep drinking water reservoir, J. Environ. Sci. (2016), http://dx.doi.org/10.1016/j.jes.2016.05.006