



# Impacts of water level regulation on sediment physic-chemical properties and phosphorus adsorption–desorption behaviors



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## ABSTRACT

Impacts of artificial water level (WL) regulation on permanently submerged and intermittently submerged sediment physic-chemical properties and phosphorus adsorption–desorption behaviors were examined. Due to organic matter (OM) loss, median size (MS) and specific surface area (SSA) of sediment particles were significantly increased and decreased with increasing WL regulation velocities, respectively. Regardless of submerged sediment types, WL regulation decreased and increased the proportion of sediment particles with size smaller and bigger than 20  $\mu\text{m}$ , respectively. Film-diffusion was the rate-limiting step and physic processes dominated phosphorus adsorption. WL regulation greatly increased sediment amorphous iron oxides (Feox) and amorphous aluminum oxides (Alox) concentrations, which subsequently caused 2.03–390.75 mg/kg improvement in Langmuir obtained maximal phosphorus adsorption capacity, and 25.81–50.00% decline in phosphorus adsorption buffering capability.

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## 1. Introduction

Natural and artificial WL regulations are two main contributors to WL fluctuation in surface water bodies such as lakes and reservoirs. Natural WL variation is greatly determined by precipitation and evaporation processes, and shows the characteristics of unstable, short duration and seasonal variability (Wu et al., 2009). However, artificial WL regulation is associated with long durations and variable water level amplitudes. Nowadays, water transfer between regions has been widely used in developing countries to mitigate the crisis of water resource shortage. As a centralized drinking water supply source, between 95 and 130 billion  $\text{m}^3$  of water are annually extracted from the Danjiangkou Reservoir, Hubei Province to North of China since 2014 (Li et al., 2009). This typically results in WL amplitude fluctuations of approximately 30 m; i.e. difference between 145 and 175 m). Accompanied the increase in storage capacity, sufficient nutrient loads and slow water flow favored the algal production, and eutrophication has

already become the most urgent ecological problem for the Danjiangkou Reservoir (Tang et al., 2012).

Sediment is one of the most important ecological components of lakes and reservoirs. Water level regulation can alter the physical and chemical characteristics of sediment, and affect the nutrient migration and circulation processes. In light of the differences in duration time and frequency of the drying and wetting cycle, sediment subjected to WL regulation can be categorized into occasionally submerged, intermittently submerged and permanently submerged sediments.

As the most representative submerged sediment types, intermittently submerged sediment and permanently submerged sediment are separately employed to study the process of nutrient release, migration and transformation under constant or approximately constant WL conditions (Li and Huang, 2010; Qian et al., 2011). Simulated static WL boundary conditions with or without disturbance are widely researched by the aforementioned researchers. However, such an approach hardly reflects the actual WL dynamics. It follows that there is still uncertainty of the impacts of WL regulation on the environmental behavior of sediments. Moreover, WL regulation can simultaneously influence the intermittently submerged and permanently submerged sediments within the same water body. Therefore, isolated research on individual submerged sediment will not necessarily shed light

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generically on the continuous and relevant impacts of WL manipulation on sediment nutrient geochemistry.

Natural WL variation usually leads to the air-drying and re-wetting of the sediments, and exhibits controversial effects on sediment phosphorus adsorption. Wang et al. (2006) reported that flooding and subsequent air-drying resulted in 369 mg/kg increase in soil phosphorus adsorption capacity. Vicente et al. (2010), however, observed that WL variation significantly reduced the phosphorus adsorption capacity of the sediment in oligotrophic high mountain lakes, and the change appeared to be non-reversible. It can be concluded that phosphorus adsorption to sediment associated with natural WL fluctuation is rather complex with different physical and chemical processes involved.

Physical change due to natural sediment flooding or drying has been described elsewhere. Barrow and Shaw (1980) found that sediment drying increased the SSA of iron oxide particles. Contrarily, Qiu and McComb (2002) described that particle size distribution in dried sediment shifted toward larger. Similar finding was also obtained by Kang et al. (2010), who conducted a 2-year in situ investigation in WL fluctuation zone of the Three George Reservoir, and found that drying-flooding process would increase the density, but reduce the porosity and water holding capacity of submerged soils.

Among the sediment chemical changes caused by WL regulation, most studies focused on the variation of sediment pH values, OM contents and transformation of iron oxide pools. After flooding, pH values are found to increase and decrease for acid and alkaline submerged soils (Zhang et al., 2004), respectively. Furey et al. (2004) observed a significant OM loss of the sediment in both lake and drinking water source reservoir with varying WL. Furthermore, decrease in WL promotes the transformation of iron oxide pools as a consequence of increasing oxygen availability. Non-crystalline iron oxides presented in previously anoxic zones are rapidly oxidized to amorphous ferric oxy-hydroxides, which has a high affinity for phosphorus (De Groot and Van Wijck, 1993).

WL fluctuations in lakes and reservoirs are dominant forces controlling the functioning of the ecosystems, and the greatest number of the publications on WL fluctuation has been carried out on macrophytes, followed by algae, zooplankton, invertebrates and fish (Leira and Cantonati, 2008). Phosphorus has been identified as a key limiting factor for eutrophication in the Danjiangkou Reservoir (Li et al., 2009), however, the impacts of WL fluctuation on sediment compositions and its relation to phosphorus environmental behaviors is still problematic.

Field investigations and enclosure experiments are useful to obtain first hand data to reveal the real impacts of WL regulation on nutrient release from sediment. However, such research schemes are usually time-consuming, costly and hamper the normal operation and management of lakes and reservoirs. In contrast, inexpensive indoor simulation experiments provide an alternative for easy control of the environmental boundary conditions and WL variation cycles. Thus, appropriate WL variation dynamic experiments should be a prior choice to preliminarily explore the change in environmental behaviors for sediment subjected to WL regulation.

In order to assess the phosphorus adsorption characteristics within lake and reservoir sediments subjected to artificially varying WL, indoor dynamic WL regulation experiments with intelligent peristaltic pumps were conducted for permanently submerged and intermittently submerged sediment. The present study aims to:

- assess the variability in pH, OM, MS, SSA, Feox and Alox of the sediment subjected to various WL regulating modes;

- identify the impacts of artificial WL regulating on sediment phosphorus adsorption–desorption behaviors; and
- explore the response of change in physic–chemical properties to the variation of phosphorus adsorption on sediment subjected to WL regulating.

## 2. Materials and methods

### 2.1. Experiment preparation and WL regulating simulation

In May 2013, permanently submerged and intermittently submerged sediment samples were collected from the Shendinghe Estuary (32°48'26" N, 110°53'44" E) 2 m lower and 1 m higher than the water surface, and corresponding overlying water were collected at an approximate depth of 30 cm as representative water samples (Ministry of Environmental Protection, 2002) around the permanently submerged sediment sampling sites. The measured water chemical oxygen demand-based permanganate index (CODMn), total nitrogen (TN) and total phosphorus (TP) concentrations were 7.44, 7.84 and 0.39 mg/L, respectively.

Six analogous 2 L glass columns (10 cm in diameter and 48 cm in height) were categorized into group A (A1, A2 and A3) and group B (B1, B2 and B3). Fully mixed permanently submerged and intermittently submerged sediment of 10-cm depth were placed into columns A and B, respectively. Reservoir water was slowly and carefully added to each column, which was previously filled with sediment up to 2 cm below the top rim. Among the six columns, columns A1 and B1 were used as controls with a constant WL of 36 cm, while the other four columns experienced three WL regulation cycles and each single cycle comprised of four WL dynamic phases: decline, stable, ascend and re-stable (Fig. 1).

For simulating the WL descending or ascending phase, intelligent peristaltic pumps were transferring overlying surface water between the water column and the separate glass container with a volume of 2 L at velocities of 3 cm/d and 6 cm/d, respectively. During the experimental period, the identical maximum WL in each column was 36 cm while the minimal WL reached approximately 0 cm for columns filled with intermittently submerged sediment. For columns packed with permanently submerged sediment, the lowest WL of either 3 or 6 cm was applied (Fig. 1). All experiments were conducted indoors at constant temperatures of 25 °C and with parallel designs. Water that was lost from the open columns due to natural evaporation got recharged on a daily basis with pure water.

Once the WL manipulation experiments were finished, sediments contained within each column were air-dried after extracting the overlying water. A 2-cm surface sediment sample before and after WL regulating was then powdered and subsequently sieved with 100- $\mu$ m diameter meshes before analysis.

### 2.2. Sediment physic-chemical properties determination

pH and OM were determined for all the sediment samples according to the Chinese Soil Physical and Chemical Standard Methods (Bao, 2000). Feox and Alox were analyzed by extracting with 0.1 mol/L  $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$  + 0.2 mol/L  $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$ , and iron and aluminum content contained in the solution were then determined using phenanthroline spectrophotometric method (Bao, 2000) and aluminon spectrophotometric method (Shao et al., 1998), respectively. BET (Brunauer–Emmett–Teller) surface area was measured using a Nova 4200e surface area analyzer from Quantachrome Instruments. Sediment particle size distribution was determined using a HORIBA-950V2 laser diffraction particle size analyzer.

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