



# Phosphorus uptake by suspended sediments from a heavy eutrophic and standing water system in Suzhou, China



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## ABSTRACT

Phosphorus (P) uptake by suspended sediments, from a heavy eutrophic canal system with high P concentration, was conducted in the lab. Addition of  $\text{KH}_2\text{PO}_4$  into the parallel operated experimental units were made similar to the external P input into the canal and carried out periodically. Results of P uptake after 39 days show that added P with the amount of 19.97 mg and 13.61 mg disappeared from the overlying water to 200 g wet sediments under intermittent disturbance and static conditions, respectively. Sequential fractionation indicated that P adsorption by Ox-Fe and Ox-Al might be the dominant P removal mechanism in the system. After P uptake under intermittent disturbance conditions, P adsorption experiment shows that the sediment was saturated with P very slowly (17.49%), compared with the sediment under static conditions (31.60%). Moreover, this sediment exhibited lower values for the constants  $K$  and  $S_0$ . It was attributed to the redistribution of different P forms in the sediment. Therefore, the sediment was expected to present a lower P release potential than that under static conditions. After 6 weeks of anoxic incubation, the percentages of the P cumulative release from both sediments to the incorporated P confirmed this. It was suggested that sediment disturbance enhanced P retention in the sediment.

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## 1. Introduction

The release of phosphorus (P) from the sediments in water bodies has been studied most extensively under certain environmental conditions (Qin and Zhu, 2006; Wang et al., 2009; Schönbrunner et al., 2012). Sediments can also function as a sink for P deposit, especially in a long term (Hu et al., 2007). This has been most clearly demonstrated in shallow lakes (Qin et al., 2004; Qin and Zhu, 2006; Kelderman et al., 2007). Generally, if P concentration in overlying water is higher than its equilibrium point of sediments, P adsorption occurs (Cyr et al., 2009).

Sediment resuspension can promote the interaction of dissolved P with natural sediments, including metal oxides or hydroxides, clay minerals,  $\text{CaCO}_3$  particles and organic matter (Li et al., 2012; Tsado et al., 2012; Moazed et al., 2010). These interactions include sedimentation–deposition, sorption–precipitation and incorporation into microbial biomass. Resuspension would be expected to enhance P uptake by sediments and therefore the removal of dissolved P compounds from water would be accelerated (Li and Huang, 2010; Li et al., 2011), due to the increased interaction between P and suspended solids. Once the driving force of sediment

resuspension is removed and the sediments associated with P settle out from the water to the bottom (Nöges and Kisand, 1999; Qin et al., 2004). This suggests that the periodic resuspension of sediments would facilitate the purification of P compounds from the overlying water, because substantial amounts of P are easily retained in the sediments (Takeda and Fukushima, 2004). It appears that P uptake by sediments under resuspension conditions are often orders of magnitude higher than under static conditions.

The potential for P uptake by suspended sediments and P release from the sediments after P uptake has received almost no attention in standing, heavy eutrophic water systems with high P concentration. Much P research focuses on P exchange in shallow lakes (Wang et al., 2008, 2009). Some studies investigating sediment resuspension on the direction and magnitude of P flux concluded that sediment resuspension could accelerate P release from the sediments (Pettersson, 2001; Qin and Zhu, 2006; Hu et al., 2006), resulting in the consequent outbreak of blue-green algae bloom. Sediments can also function as a source for P release due to P previously incorporated into the sediments, depending on sedimentary P fractions with marked difference in mobility (Lai and Lam, 2008). However, after sediment resuspension, the concentrations of sedimentary P fractions are redistributed (Li and Huang, 2010). Li and Huang (2010) reported that non-occluded Fe-P and occluded Fe-P of the sediments with resuspension declined from 0.53 (Day 0) to 0.29 (the mean during resuspension), indicating the

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redistribution of sedimentary P fractions under sediment resuspension conditions. This may be attributed to the formation of crystalline iron oxides and amorphous aluminum oxides due to the higher penetration of oxygen into the sediments (Nguyen, 2000; Kraal et al., 2009) as well as the increased interactions between P and P reactants, such as iron oxides, aluminum oxides, and organic matter, under resuspension conditions. Nguyen (2000) also found that the significant proportion of sedimentary P was occluded Fe/Al-P (refractory) under mixing and oxidizing conditions. Some researchers also found that P retention occurred primarily at the oxidized sediment–water interface (Reddy et al., 1996; Qin and Zhu, 2006). As a result, these findings lead to an assumption that resuspension could enhance P retention in the sediments due to the redistribution of sedimentary P forms by increasing the penetration of oxygen and interactions between P and P reactants. Knowing the release of P from suspended sediments after P uptake is essential for the application of natural sediments to reduce P loads from eutrophic water bodies, especially standing, heavy eutrophic water systems with high P concentration.

P adsorption and retention at the sediment and water interface in water bodies is an important factor affecting its transport, bioavailability and concentration in the overlying water. Therefore, the behavior of P adsorption has been extensively studied (Jin et al., 2005; Wang et al., 2012). But the results from shallow eutrophic lakes and rivers cannot simply be applied to the suspended sediments from standing, heavy eutrophic water systems, receiving external P input. For suspended sediments, sedimentary P fractions changed due to P uptake and iron oxide increased due to penetration of oxygen, compared with the sediments found in shallow lakes and rivers. We would therefore not expect them to adsorb and immobilize P in the same way from overlying water.

The objectives of this study were to investigate P uptake by suspended sediments in laboratory experiments, in which the waters and sediments used were taken from a standing, heavy eutrophic water system, and  $\text{KH}_2\text{PO}_4$  was added with an amount equalled that of external P input periodically into the parallel operated experimental units with and without (i.e. static) intermittent resuspension. After P uptake, the sediments from the units with and without intermittent resuspension were exposed to low redox conditions in order to rapidly exhaust the pool of potentially mobile P (Schönbrunner et al., 2012). We used P sorption experiments to compare the potential of the sediments with and without intermittent resuspension after P-uptake for P release or adsorption and measured sedimentary P fractions after P-uptake. The purpose was to evaluate P retention in the suspended sediments under disturbance and external P input conditions.

## 2. Materials and methods

### 2.1. Site description

The water system is a canal, which is situated in southwestern Suzhou city ( $31^\circ 18' \text{ N}$  and  $120^\circ 33' \text{ E}$ ), China. The canal has a surface area of  $0.08 \text{ km}^2$  and maximum and mean depths of 3.30 m and 1.26 m, respectively. The length of the canal is 3.6 km and maximum and mean widths are 30 m and 22 m. Both ends of the canal are dams, resulting in the canal water standing. Although the study canal does not receive any major point source nutrient inputs, some minor point sources, such as those coming from the restaurants and the bathhouse, and nonpoint sources pose a greater danger of increasing loads in the canal. The overlying water also recorded appreciable concentrations of soluble reactive P (SRP). There are serious blue-green algae blooms in the canal every summer and autumn since 2004.

### 2.2. Sample collection and treatment

Sediments taken from the inlet ( $31^\circ 18' 29.2'' \text{ N}$  and  $120^\circ 33' 28.1'' \text{ E}$ ) of the canal were used for the experiments. Sediments were collected, using a piston corer (10 cm diameter). The surface 1 cm layer of all sediment cores was extruded and collected on site. These sediments were stored in the capped glass flasks and then transported to the laboratory immediately. These sediments were used for the chemical and physical analysis and the P-uptake experiments.

### 2.3. P-uptake experiment

Sediments (200 g wet weight) were added to a plastic container, 154 mm diameter  $\times$  300 mm high. Canal water (2.5 L) with SRP of  $0.42 \text{ mg PL}^{-1}$  was filled carefully into the container, preventing the sediments from disturbance. Two sets of containers (named E0 and E1) were used as the laboratory experiments, each set including three parallel containers. For E1, sediments were disturbed using a blender at the rate of 60 rpm for 10 min every day over a 39-day period. Keeping the sediments suspended completely during the disturbance and then suspended sediments settled for 1430 min after the disturbance finished. On the other hand, E0 was a control experiment to simulate static conditions, with nothing done to the sediments and water. The experiments were started at Day 0. Over the incubation period, 25 mL of water samples were collected regularly at 2 day intervals, filtered through  $0.45 \mu\text{m}$  polyamide filter and immediately analyzed for SRP. Distilled water was added prior to sampling to replenish the evaporative loss of canal water, while 25 mL canal water with an amount of  $\text{KH}_2\text{PO}_4$  solution was added to each container after each sampling to replace the volume of water removed. At Day 3, 6, 9, 12, 15, 18, 21, 24, the added  $\text{KH}_2\text{PO}_4$  concentration was  $1.25 \text{ mg P mL}^{-1}$  and at Day 27, 30, 33, 36, this concentration was  $2.5 \text{ mg P mL}^{-1}$ . The aim was to keep P concentration of the overlying water in both sets about  $0.5 \text{ mg PL}^{-1}$  (SRP) from Day 3 to Day 24 and  $1 \text{ mg PL}^{-1}$  (SRP) from Day 27 to Day 36, simulating the external P input into the canal. It was calculated that 20 mg P was added gradually to the water over a 39-day period.

Day 3, SRP removal was expressed as the percentage of the concentration of SRP in the overlying water at Day 3 to initial state ( $0.42 \text{ mg P mL}^{-1}$ ).

Day 6 through Day 24, SRP removal was according to the following equation.

$$\text{SRP removal}_{3(n+1)} = \frac{C_{3n} + 0.5 - C_{3(n+1)}}{C_{3n} + 0.5} \quad (1)$$

where SRP removal, is the disappeared SRP in the overlying water (%);  $C_{3n}$ , the concentration of SRP at Day  $3n$ ;  $C_{3(n+1)}$ , the concentration of SRP at Day  $3(n+1)$ ;  $n$ : 1 through 8. 0.5 is referred to the increase of P concentrations in the overlying water due to the addition of external P at Day  $3n$ .

Day 27 through Day 39, SRP removal was according to the following equation.

$$\text{SRP removal}_{3(n+1)} = \frac{C_{3n} + 1 - C_{3(n+1)}}{C_{3n} + 1} \quad (2)$$

where SRP removal, is the disappeared SRP in the overlying water (%);  $C_{3n}$ , the concentration of SRP at Day  $3n$ ;  $C_{3(n+1)}$ , the concentration of SRP at Day  $3(n+1)$ ;  $n$ : 9 through 12. 1 is referred to the increase of P concentrations in the overlying water due to the addition of external P at Day  $3n$ .

After the experiments finished, the sediments were taken from each container, and dried, ground, then sieved with a standard 100 mesh sieve for P adsorption experiment and P release experiment and chemical analysis.

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