

**Application of constructed wetland for urban lake water purification: Trial of Xing-qing  
Lake in Xi'an city, China**

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**ABSTRACT**

A comprehensive review of the current water pollution status in China has indicated that the urban lakes in Chinese cities have suffered from serious pollution and in high risk of eutrophication although the pollution sources have been largely controlled. The objective of this study lies in exploring a long term restoration of the aquatic ecosystem in Chinese city lakes using treatment wetland, an environmentally friendly and cost-effective technology. Trials from a subsurface horizontal flow constructed wetland (CW) have demonstrated that the treatment wetland can be used for such kind of purpose of lake water quality control. Average removal of 84.2% for COD, 53.8% for NH<sub>3</sub>-N, 47.9% for TN, 73.3% for TP and 86.6% for SS can be achieved. Relatively, low removal of nitrogen lies in the lack of nitrification and denitrification process. Accordingly, improved configuration of the treatment

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wetland system has been proposed and discussed. Finally, the importance of the integrated constructed wetland especially for the application of urban lake water treatment is highlighted.

**Keywords:** Constructed wetland, urban lake, wastewater treatment.

## INTRODUCTION

With the rapid development of economy and urbanization, water pollution remains the most critical problem in China today. In particular, eutrophication in lakes (such as Taihu Lake, Dianchi Lake, and Chaohu Lake) <sup>[1,2]</sup> including thousand of urban lakes have shown the most grievous examples of this phenomenon. Urbanization, industrial development, and deficient waste disposal practices may be the most important factors to cause the urban lakes pollution.

One the other hand, vast amounts of studies have demonstrated that constructed wetland (CW) offers promising prospective for the treatment of different kinds of wastewaters, which include domestic, industrial and agricultural effluents, storm runoff, mine drainage and landfill leachate. <sup>[3]</sup> Compared with other technologies, e.g. activated sludge, tricking filter and biological reactors, CW has the advantage of aesthetical appearance and lower energy consumption. Accordingly, it has been termed as a ‘green’ wastewater treatment technique and thus contributed to sustainable development. It has been noted from the literature that there is a lack of using CW for water pollution control in urban lake. <sup>[4]</sup> In addition, urban lake water qualities often vary from site to site and from year to year. Therefore results obtained from any study of urban lake water treatment via CW are specific to the particular location of the lake and its season. For these reasons results of the trial in one location of the urban lake cannot be accurately extrapolated for different locations/cities across the country.

Therefore, it is wiser to conduct specific site-related trial of urban lake water treatment via CW before any large scale application is planned.

The objective of this study was to examine the performance and effectiveness of CW for an urban lake, namely Xing-qing Lake in central Xi'an city, Shannxi province, China, water pollution control. Results from the experiment of a subsurface horizontal flow CW in a continuous operation in two seasons of autumn and winter were presented. Relevant issues of the further study and possible larger application are proactively discussed.

## **MATERIALS AND METHODS**

### ***Xing-qing Lake and its water quality***

Xing-qing Lake, located in the centre of Xi'an city, Shannxi province, is the largest artificial lake in the city. The lake was planned and built in 1956 with water volume of 170,000 m<sup>3</sup> for normal season and 270,000 m<sup>3</sup> for flooding season, respectively. The average water depth is 1.6 m with maximum depth of 2.0 m. The lake plays an important role in tourism, culture, aesthetical appearance and flood control. Due to the rapid economic and urban development over the last decades, Xing-qing Lake has sustained high stress from water pollution. Currently, there are 5 rainwater and wastewater discharge pipelines surrounding the Xing-qing Lake. This has caused a wastewater discharge to the lake with an average flow rate of 27,000 m<sup>3</sup>/day. The Xi'an city council/government has invested 75.45 million Chinese Yuan over the period from 2003 to 2010 to control the water pollution and to restore the aquatic ecosystem in the lake.

The water tested in the proposed CW system was collected from one of the entering pipelines of the Xing-qing Lake. The raw water quality was monitored and the results are listed in Table 1.

[Table 1 here]

### ***CW set-up and operation***

The CW treatment system consists of an influent tank and a subsurface horizontal flow CW (Fig. 1). The CW was set up using a three-side PVC and one-side Pyrex plate with dimensional size of 1.8m×0.6m×1.0m. The CW was filled firstly with 10-40mm sized gravel to 40 cm as the bottom layer followed by 15 cm coarse sand and 5 cm local soil (0-5 mm size) as middle and top layers, respectively. *Phragmites australis* collected from a river bank outside Xi'an city were planted on the top of the CW. The influent (see Table 1) was loaded onto the CW via a peristaltic pump from a feed tank with a hydraulic loading rate of 0.5 m<sup>3</sup>/m<sup>2</sup>.d. The treatment CW system was continuously operated for 180 days in an open experimental site in autumn and winter seasons to explore the treatment efficiency and the effectiveness of the season's change, particularly in the cold climate, to the removal behaviour. In addition, effects of the hydraulic retention time (HRT) were also examined during the experimental period. This will help to provide the useful information on treatment wetland system configuration in possible large scale application in the special case of urban lake water treatment.

[Fig. 1 here]

Samples of influent and effluent from the treatment wetland were collected and analysed periodically for COD, NH<sub>3</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, TN, TP, pH and SS. COD was measured using a Hach DR/4000 spectrophotometer. The P analysis was based on the reaction of orthophosphate in the samples with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. NH<sub>3</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N, TN, pH and SS were monitored according to the standard method. <sup>[5]</sup>

## RESULTS

### *Overall treatment performance*

The overall treatment performance of the wetland system was illustrated in Figure 2. Under the hydraulic loading rate of  $0.5 \text{ m}^3/\text{m}^2\cdot\text{d}$ , the treatment wetland has exhibited a good treatment performance. Average removal of 84.2% for COD, 53.8% for  $\text{NH}_3\text{-N}$ , 47.9% for TN, 73.3% for TP and 86.6% for SS can be achieved. Average effluent with 17.6 mg/L COD, 1.3 mg/L  $\text{NH}_3\text{-N}$ , 0.93mg/L TN, 0.24mg/L TP was monitored. Satisfied COD removal indicated the integrated processes inside the treatment wetland, which possibly include filtration, sedimentation, adsorption, plant uptake and more importantly, the biological degradation of the organics from the influent. SS removal is mainly from the filtration and sedimentation while TP removal can be mainly contributed to adsorption onto the wetland substrate. <sup>[6]</sup> It is noted from Fig. 2 that the removal of  $\text{NH}_3\text{-N}$ , TN and TP exhibited considerable fluctuation. Significantly, the relative low removal of  $\text{NH}_3\text{-N}$  and TN suggests the inadequate process of oxidation in the system, which can also be indicated from the insignificant change of pH between influent and effluent. In addition, measurement of  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$  also showed an insignificant change or increase in effluent compared with that in influent.

[Fig. 2 here]

### *Effects of hydraulic retention time on treatment performance*

Figure 3 illustrates the effects of HRT on treatment performance of the wetland system. It shows a trend that the treatment performance gets better as the HRT becomes longer especially for the HRT being increased from 8 hrs to 48 hrs. There is no benefit for HRT to be further increased from 48 hrs to 72 hrs with TP removal as an exception since TP removal

mainly depends on substrate adsorption in which known knowledge has advised complete adsorption being achieved with longer contacting time. However, longer HRT may lead to the serious anaerobic condition in the system, resulting in the decrease of treatment efficiency.

**[Fig. 3 here]**

### ***Effects of season/temperature on treatment performance***

Figure 4 jointly illustrates the overall performance of the treatment wetland in autumn and winter. During the experimental seasons, in autumn, the air temperature ranged 4~23 °C with average of 13.5 °C while the water temperature ranged 11.6~19.3 °C with average of 15.5 °C. In winter, the air temperature ranged -5~17 °C with average of 6.0 °C while the water temperature ranged 1.8~12.6 °C with average of 7.2 °C. It can be seen from Figure 4 that with the decrease of water's temperature, it seems no obvious negative effect on COD, TP and SS removal. However, reduction of NH<sub>3</sub>-N and TN removal was remarkably observed.

Compared with the performance in autumn, removal efficiency of NH<sub>3</sub>-N and TN was reduced for 20.5% and 33.8%, respectively; this indicates the significant reduction of the bacteria activity particularly for nitrification related bacteria which were believed to be developed as attached growth onto the wetland substrate. Therefore, caution should be taken in the operation of the treatment system in winter. Necessary technical and operational actions such as lowering loading, effluent recirculation and temporary aeration as supplement would be considered.

**[Fig. 4 here]**

## DISCUSSION

The current study is trying to explore the constructed wetland technology as a solution for urban lake water quality improvement to couple with the attempted restoration of the aquatic ecosystem in Chinese cities. By taking Xing-qing Lake in Xi'an city as an example, the trial of the subsurface horizontal flow CW has demonstrated the success of the treatment performance especially in autumn and winter seasons. High removal of organics (termed as COD), TP and SS and considerable removal of  $\text{NH}_3\text{-N}$  and TN were achieved, which are comparable to other studies reported in the literature for subsurface horizontal flow CW.<sup>[7-9]</sup> As has been shown in Figures 2 to 4, the treatment wetland system under study showed a low removal of  $\text{NH}_3\text{-N}$  and TN, suggesting a weak nitrification process. This is because the most nitrobacteria belong to aerobic and facultative autotrophic bacteria, one of whose prominent characteristics is slow multiplication and long generation time.<sup>[10]</sup> Therefore, multi-stage wetland system can be reasonably suggested for further study and possible large application. Multi-stage wetland system allows the growth of different kinds of bacteria in different stage and thus enhances the nitrification and denitrification process.<sup>[11]</sup> Treated municipal wastewater from the municipal wastewater treatment plant (MWWTP) or sometimes mixed with rainwater should be introduced to the multi-stage wetland system for further purification before entering to the lake. This treatment strategy and system configuration is schematically illustrated in Figure 5(a).

Regarding the effect of HRT on treatment wetland, findings from this study agree with that from the literature, i.e. longer HRT can lead to better treatment efficiency.<sup>[12,13]</sup> The alternative option to achieve this is the effluent recirculation. Studied from the literature have shown ample evidence that recirculation of treated wastewaters has a positive effect on pollutants removal especially on total nitrogen removal within treatment wetlands. For example, Kantawanichkul et al.<sup>[14]</sup> showed that the recirculation of effluent in a hybrid

treatment wetland system increased the total nitrogen removal rate from 71% to 85%. Similar studies have been reported by Zhao et al.<sup>[15]</sup> and Stefanakis and Tsihrintzis.<sup>[16]</sup> Findings from a pilot-scale study in China reported by He et al.<sup>[17]</sup> showed increased NH<sub>3</sub>-N removal rates in comparison to non-recirculated effluent. In particular, Humenik et al.<sup>[18]</sup> reported that nitrified lagoon water added to treatment wetland microcosms led to nitrogen removal rates that were four to five times those of non-nitrified liquid. Bearing this in mind, with regard to the urban lake water treatment, the recirculation can be done by either recycling the effluent back into the treatment wetland system or the addition of the lake water, which may be partially-nitrified and possibly have more dissolved oxygen to improve the bio-oxidation in the treatment wetland system. This treatment strategy and system configuration is schematically illustrated in Figure 5(b).

**[Fig. 5 here]**

In the special situation of urban lake in the city, application of treatment wetland should be considered not only to achieve satisfied treatment efficiency, but also to fit the aesthetical appearance as a whole of the wetland system and the lake water to the surrounding environment of the city. This recalls the state of the art concept of integrated constructed wetland (ICW) reported by Scholz et al.<sup>[19]</sup>, Harrington and McInnes<sup>[20]</sup> and Harrington and Scholz.<sup>[21]</sup> The ICW concept is a holistic approach to the design of treatment wetlands that take economic, social, environmental and landscape aesthetic aspects into consideration in their design, construction and operation.<sup>[21]</sup> Moreover, the incorporation of wetlands into the landscape enhances biodiversity.<sup>[19,20]</sup> Clearly, the ICW is a very important concept for the application of treatment wetland in urban area including urban lakes.



## CONCLUSIONS

As a solution to prevent the increased pollution and eutrophication in urban lakes in China, CW was adopted for a trial of mixed wastewaters entering the Xing-qing Lake in Xi'an city. Results from a subsurface horizontal flow CW have demonstrated that the treatment wetland can be used for such kind of purpose for lake water quality control. Average removal of 84.2% for COD, 53.8% for  $\text{NH}_3\text{-N}$ , 47.9% for TN, 73.3% for TP and 86.6% for SS can be achieved. Nitrification and denitrification were not the major process since the  $\text{NH}_3\text{-N}$  and TN reduction is marginal particularly in winter operation period. Therefore, multi-stage CW system with effluent and lake water recirculation has been proposed for further study. In addition, application of treatment wetland system in urban lake water treatment should consider the newly developed concept of ICW, which takes economic, social, environmental and landscape aesthetic aspects into consideration in wetland design, construction and operation.

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## REFERENCES

[1] Qu, J.; Fan, M. The current state of water quality and technology development for water pollution control in China, *Crit. Rev. Environ. Sci. Technol.* **2010**, *40*, 519-560.

- [2] Li, S.; Li, H.; Liang, X.Q.; Chen, Y.X.; Wang, S.X.; Wang, F.E. Phosphorus removal of rural wastewater by the paddy-rice-wetland system in Tai Lake Basin, *J. Hazard. Mater.* **2009**, *171*(1-3), 301-308.
- [3] Garcia, J.; Rousseau, D.P.L.; Morato, J.; Lesage, E.; Matamoros, V.; Bayona, J.M. Contaminant removal processes in subsurface-flow constructed wetlands: a review, *Crit. Rev. Environ. Sci. Technol.* **2010**, *40*, 561-661.
- [4] Vymazal, J.; Kropfelova, L. *Wastewater treatment in constructed wetlands with horizontal sub-surface flow*. Environmental Pollution Series, Vol. 14. Dordrecht, the Netherlands: Springer, 2008.
- [5] Ministry of Environmental Protection of the People's Republic of China. Monitoring Analysis Methods for Water and Wastewater (the Fourth Edition). Beijing, National Environmental Science Press. 2002.
- [6] Ballantine, D.J.; Tanner, C.C. Substrate and filter materials to enhance phosphorus removal in constructed wetlands treating diffuse farm runoff: a review, *New Zealand J. of Agri. Res.* **2010**, *53*(1), 71-95.
- [7] Albuquerque, A.; Oliveira, J.; Semitela, S.; Amaral, L. Evaluation of the effectiveness of horizontal subsurface flow constructed wetlands for different media, *J. Environ. Sci.* **2010**, *22*, 820-825.
- [8] Akratos, C.S.; Papaspyros, J.N.E.; Tsihrintzis, V.A. Artificial neural network use in ortho-phosphate and total phosphorus removal prediction in horizontal subsurface flow constructed wetlands, *Biosystems Eng.* **2009**, *102*, 190-201.
- [9] Vohla, C.; Alas, R.; Nurk, K.; Baatz, S.; Mander, Ü. Dynamics of phosphorus, nitrogen and carbon removal in a horizontal subsurface flow constructed wetland, *Sci. Total Environ.* **2007**, *380*, 66-74.

- [10] Kadlec, R.H.; Wallace, S. *Treatment Wetlands*, 2<sup>nd</sup> edition CRC Press, Raton, FL. USA, 2009.
- [11] Babatunde, A.O.; Zhao, Y.Q.; Zhao, X.H. Alum sludge-based constructed wetland system for enhanced removal of P and OM from wastewater: Concept, design and performance analysis, *Bioresour. Technol.* **2010**, *101*, 6576-6579.
- [12] Garcia, J.; Vivar, J.; Aromir, M.; Mujeriego, R. Role of hydraulic retention time and granular medium in microbial removal in tertiary treatment reed beds, *Water Res.* **2003**, *37*, 2645-2653.
- [13] Akratos, C.S.; Tsihrintzis, V.A. Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands, *Ecol. Eng.* **2007**, *29*, 173-191.
- [14] Kantawanichkul, S.; Neamkam, P.; Shutes, R.B.E. Nitrogen removal in a combined system: vertical vegetated bed over horizontal sand bed. *Water Sci. Technol.* **2001**, *44* (11-12), 137-142.
- [15] Zhao, Y.Q.; Sun, G.; Allen, S.J. Purification capacity of a highly loaded laboratory scale tidal flow reed bed system with effluent recirculation, *Sci. Total Environ.* **2004**, *330*, 1-8.
- [16] Stefanakis, A.I.; Tsihrintzis, V.A. Effect of outlet water level raising and effluent recirculation on removal efficiency of pilot-scale, horizontal subsurface flow constructed wetlands, *Desalination*, **2009**, *V248*(1-3), 961-976.
- [17] He, L.S.; Liu, H.L.; Xi, B.D.; Zhu, Y.B. Enhancing treatment efficiency of swine wastewater by effluent recirculation in vertical-flow constructed wetland. *J. Environ. Sci.* **2006**, *18*, 221-226.
- [18] Humenik, F.J.; Szogi, A.A.; Hunt, P.G.; Broome, S.; Rice, M. Wastewater utilization: a place for managed wetlands—review, *Asian–Australasian J. Animal Sci.* **1999**, *12*(4), 629-632.

[19] Scholz, M.; Harrington, R.; Carroll, P.; Mustafa, A. The integrated constructed wetlands (ICW) concept. *Wetlands*, **2007**, *27*(2), 337-354.

[20] Harrington, R.; McInnes, R. Integrated constructed wetlands (ICW) for livestock wastewater management. *Bioresour. Technol.* **2009**, *100*, 5498-5505.

[21] Harrington, C.; Scholz, M. Assessment of pre-digested piggery wastewater treatment operations with surface flow integrated constructed wetland systems, *Bioresour. Technol.* **2010**, *101*, 7713-7723.

**Figure captions:**

**Figure 1.** Schematic description of the testing constructed wetland

**Figure 2.** Overall performance of the treatment wetland system

**Figure 3.** Effects of HRT on the performance of the treatment wetland system

**Figure 4.** Effects of season on the overall performance of the treatment wetland system

**Figure 5.** The layout of the proposed CW configuration for urban lake water treatment

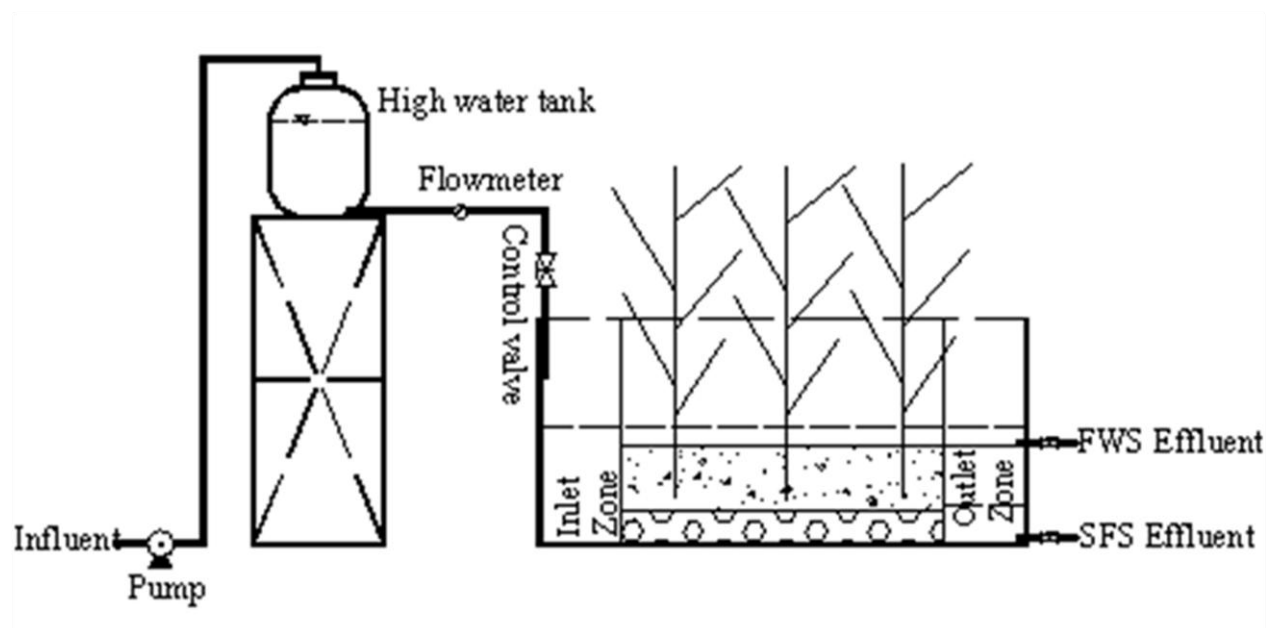


Fig. 1

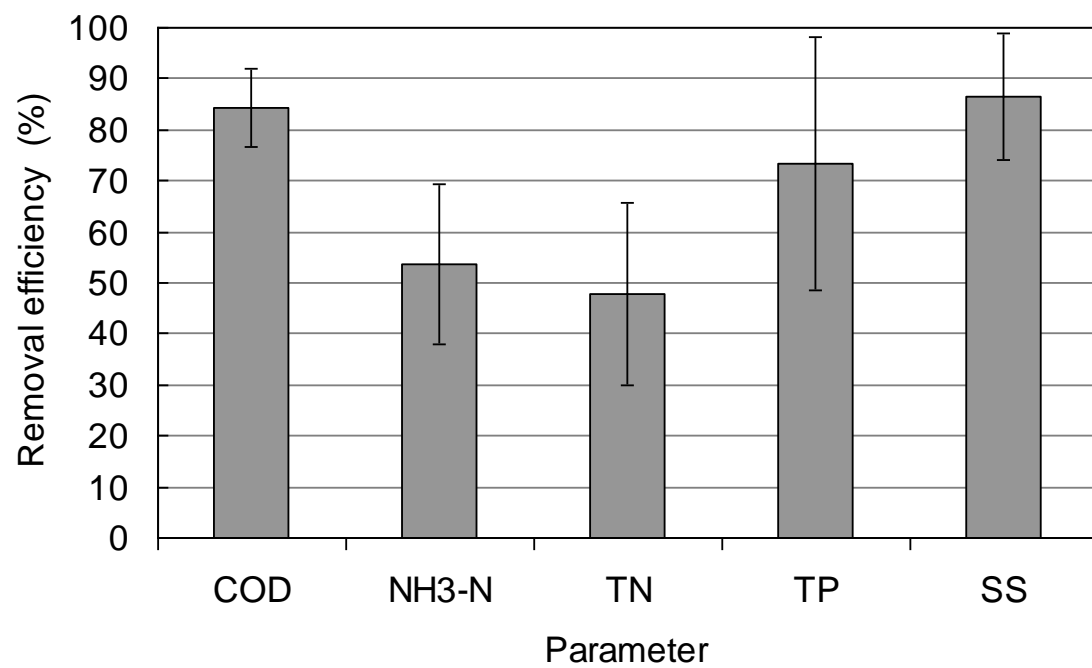


Fig. 2

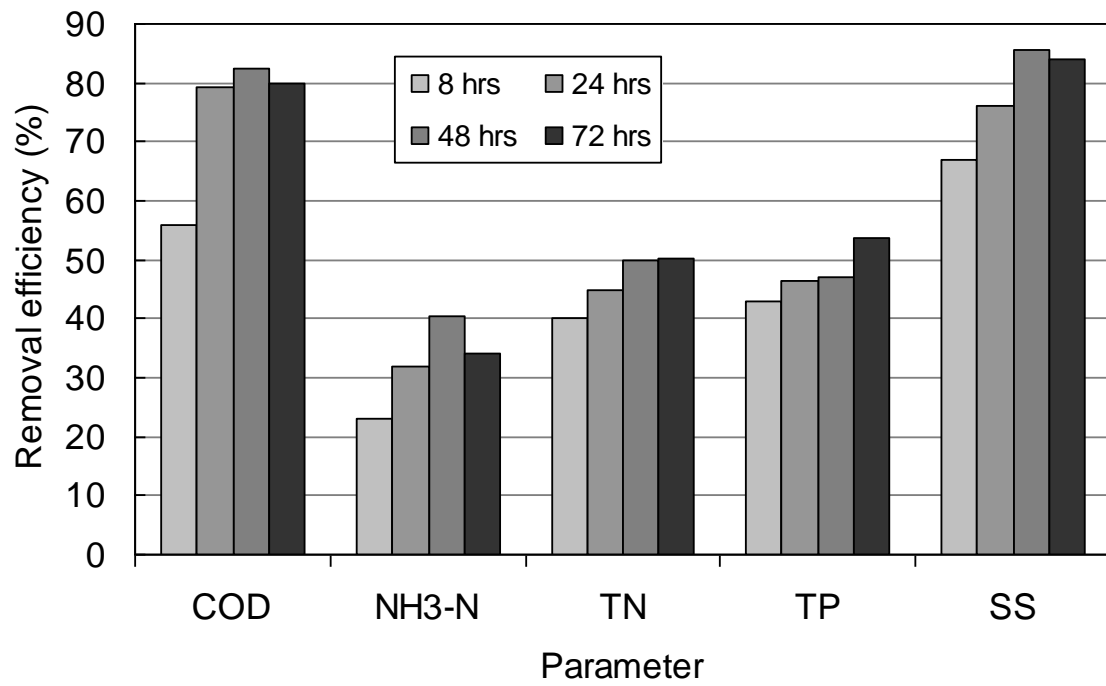


Fig. 3

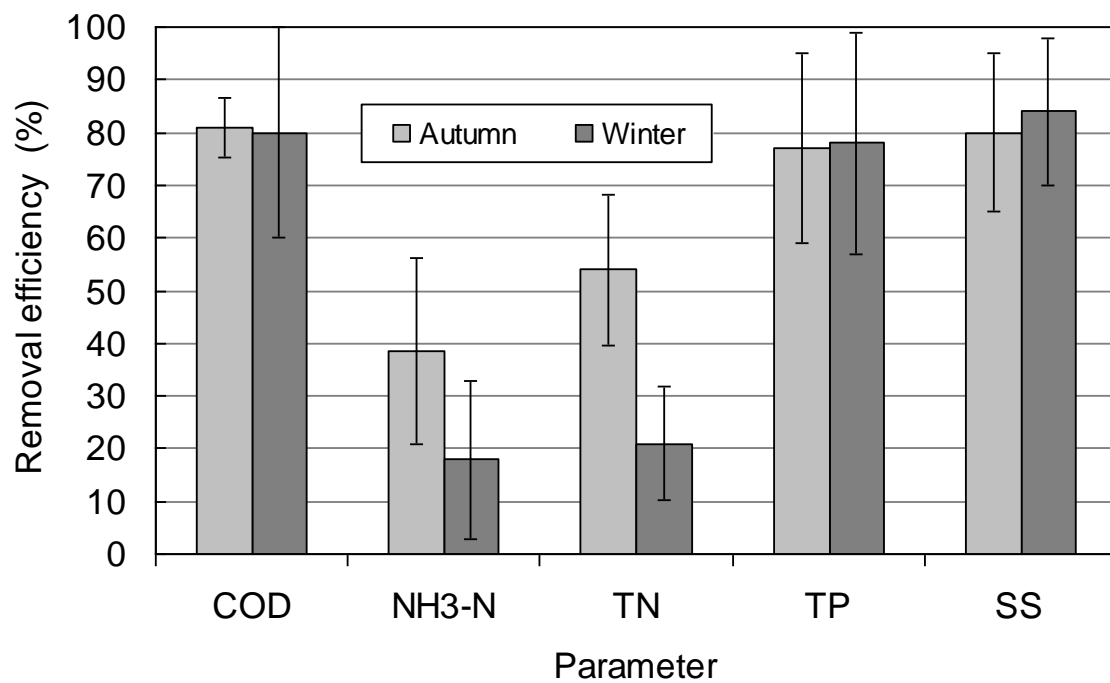


Fig. 4

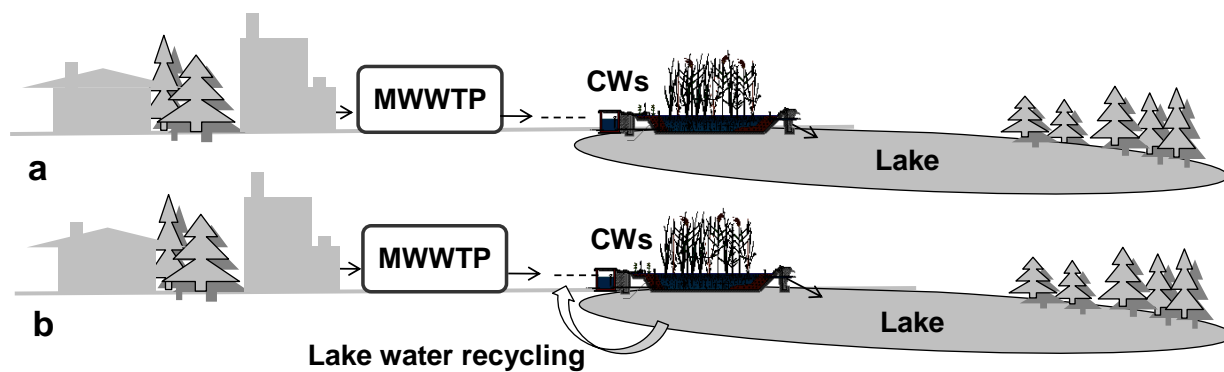


Fig. 5

**Table 1** Water quality of Xing-qing Lake

Parameter	Range (mg/L)	Mean (mg/L)	Parameter	Range (mg/L)	Mean (mg/L)
SS	65~331	198	TP	0.34~1.43	0.885
pH	7.21~8.75	7.98	TN	0.43~1.86	1.15
COD <sub>cr</sub>	59.5~135.0	97.22	NO <sub>3</sub> <sup>-</sup> -N	0.15~0.44	0.295
NH <sub>3</sub> -N	1.41~5.65	3.53	NO <sub>2</sub> <sup>-</sup> -N	0.13~0.79	0.46