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Engineering Practice for *in Situ* Repair of Polluted Water in Urban Lakes: the Example of Shuanglong Lake*

GUO Xiang[1], ZHONG Cheng-hua[2], WANG Xiao-xue[2], CHEN Long[2]
(1. College of Chemistry and Chemical Engineering of Southwest University, Chongqing 400715;
2. College of Environmental and Biological Engineering of Chongqing T&B University, Chongqing 400067, China)

Abstract: This paper describes the pollution condition and causes of the eutrophication of Shuanglong Lake prior to its management and introduces measures for comprehensive *in situ* repair (such as lake interception, ecological dredging, reoxygenation measures, slope care, ecological reconstruction and landscape restoration of the lakefront, later-stage management, and other measures). The study reports the effects of water purification after the implementation of these comprehensive *in situ* repair measures. The results show that these repair measures have been effective in controlling the eutrophication of Shuanglong lake, and this study therefore provides methods and technical reference for the management of urban lake eutrophication at home and abroad.

Key words: Shuanglong Lake; eutrophication; in situ comprehensive repair measures; effectiveness
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Urban Lakes are scenic spots and places to enjoy leisure activities. Urban lakes also have unique ecological functions; they are described as "the city's kidney". In recent years, due to the accelerated pace of urbanization, many urban lakes have become polluted to varying degrees. According to surveys, most indicators of water quality in lakes such as West Lake, Xuanwu Lake and Daming Lake in China's major cities are Class Ⅴ (the highest pollution class). Lake pollution has serious effects on the productivity, quality of life, and learning of the residents who live around the lake.

The causes of pollution of urban lakes pollution are massive discharges of industrial and domestic pollutants, weak environmental awareness of residents and visitors, and lack of discovery of suitable solutions for curbing water pollution.

1 The Basic Situation of Shuanglong Lake

The original name of Shuanglong Lake is "half ditch reservoir" and it was constructed in 1964. During the development of the northern area of the city in 1992, the name was changed. The lake twisted and turned, shaped like two dragons playing in the water, so its name then became Shuanglong (Pair of Dragons) Lake. The main functions of the lake are urban landscaping and recreation. Shuanglong Lake is a shallow city lake located on Shuanglong Street in the Yubei District of Chongqing. It has a drainage basin of 1.35 km^2, a total designed capacity of 96.0 million cubic meters, effective capacity of 740 000 cubic meters,

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First author biogeaphy: GUO Xiang, male, M. S., mainly engaged in water treatment research. **Corresponding author**: ZHONG Cheng-hua, E-mail: zhong. chenghua@163. com

and surface area of 17 ha. The average depth is 4.4 m; the greatest depth 13 m, and the shallowest part is 1 m deep. It is a core component of the urban environment and a scenic feature of the Lianglu region of the city in which it lies. Its ecological functions are therefore very important.

In recent years, however, the rapid economic development and associated construction boom in the city has seriously polluted Shuanglong Lake with domestic sewage, industrial waste water, building waste water and boating waste water all pouring into the lake. This has caused serious pollution and affected the city landscape around Shuanglong Lake as well as seriously affecting the living and working conditions of the lakeside residents.

Some water quality monitoring results provided by Yubei District Environmental Protection Bureau and the Chongqing Municipal Environmental Monitoring Center for February 2008, March 2009, and January 2010 are shown in Tab. 1.

These monitoring results show that the water quality of Shuanglong Lake was Class V or below for the period 2008—2010. The main indicators that are in excess are *TN*, *TP*, COD_{cr}, as well as total nitrogen and total phosphorus. These concentrations are far beyond the levels that cause lake eutrophication and as a result Shuanglong Lake water was severely eutrophic at this time.

Tab. 1 Water quality monitoring results for Shuanglong Lake before management mg · L^{-1}

Section	Time	Water quality	Index	COD_{Cr}	NH_3-N	*TN*	*TP*
Dyke	2008 whole year	Worse than Ⅴ	Mean	40.38	0.309	1.823	0.137
			Level	Worse than Ⅴ	Ⅱ	Ⅴ	Ⅴ
	2008.2	Worse than Ⅴ	Data	33.60	0.045	2.140	0.192
			Level	Ⅴ	Ⅰ	Worse than Ⅴ	Ⅴ
	2009.3	Worse than Ⅴ	Data	47.5	0.147	3.33	0.449
			Level	Worse than Ⅴ	Ⅰ	Worse than Ⅴ	Worse than Ⅴ
Jinghu garden	2008 whole year	Worse than Ⅴ	Data	40.63	0.290	1.726	0.123
			Level	Worse than Ⅴ	Ⅱ	Ⅴ	Ⅴ
	2008.2	Worse than Ⅴ	Data	37.20	0.027	2.150	0.149
			Level	Ⅴ	Ⅰ	Worse than Ⅴ	Ⅴ
	2009.3	Worse than Ⅴ	Data	47.7	0.147	2.25	0.370
			Level	Worse than Ⅴ	Ⅰ	Worse than Ⅴ	Worse than Ⅴ
Middle of the lake	2010.1	Worse than Ⅴ	Data	18.0	0.604	2.85	0.318
			Level	Ⅲ	Ⅲ	Worse than Ⅴ	Worse than Ⅴ

2 Analysis of Causes of Shuanglong Lake Pollution

The causes of eutrophication of Shuanglong Lake can be classified in two categories: point source and non-point source pollution. Point sources are the major sources of pollution and include industrial wastewater and sewage. Non-point pollution sources include surface runoff from construction sites and discharges in stormwater runoff channels.

3 *In Situ* Restoration Projects and Postregulatory measures for Shuanglong Lake

Shuanglong Lake's eutrophication problem attracted great attention from the Yubei District Government and the general residents. The District Government decided to rectify the problem thoroughly and radically improve the ecological environment of the lake.

Commissioned by the Yubei District Government of Chongqing, we have mainly taken the approach of *in*

situ restoration to achieve satisfactory long-term treatment effects. The project was based on both field investigation and water quality assessment of the lake. In this way we combined a variety of technical methods with a comprehensive management approach.

The main principles for the *in situ* restoration of Shuanglong Lake include both governance measures and management measures for: water improvement combined with slope renovation, landscape construction combined with environmental protection, recreational construction combined with ecological construction, conventional means combined with ecological management, and construction combined with scientific management.

3.1 Engineering measures

3.1.1 *Ecological dredging* We used a YFCS-60 eco-dredging vessel equipped with a YFFL-100 sediment separator for dredging during the dry season. The benefits of this approach were to reduce the concentration of nutrients in the lake, increase the storage capacity and environmental carrying capacity of the lake, improve the water quality and ecological environment of the lake, improve the available efficiency, delay the aging of the lake, provide fertilizer in the form of sediment, improve soil quality, and increase the outputs of agricultural and forestry products.

3.1.2 *Reoxygenation measures* Aeration of lake water was improved by using sight-seeing boats, inflatable oxygen exposure and new mobile aeration equipment. We also established safety enclosures around the aerators to prevent tourists approaching them, thereby eliminating security risks. The benefits included increased water flow and uptake of dissolved oxygen, thereby improving the auto-purification capacity of the lakes, and avoiding the recurrence of algal blooms in the water.

3.1.3 *Bottom drainage measures* First, in the center of the lake we set three 200 mm diameter by 100 m long bottom drain pipelines. Second, for improving the scheduling of this underlying drainage according to the patterns of season and rainfall, we took bottom drainage measures in advance of flooding and in this way could alleviate flooding and provide more capacity for the lake. The benefits include improving the intensity of drainage, strengthening the capacity for timely drainage, extending the radiation of drainage, and strengthening the capacity for decontamination by means of drainage.

3.2 Ecological engineering measures

3.2.1 *Slope care* Dependent on the actual situation of the various areas of the embankment of Shuanglong Lake, we planted large areas of trees and grass covering a total area of 5000 m^2 or so. We used willow which can hold the soil with its strong roots, gradually replacing bamboo and broadleaved deciduous trees so as to limit the pollution of the water body by fallen leaves. The benefits include holding the soil, reducing non-point source pollution, and enhancing the beauty of the landscape.

3.2.2 *Stocking of aquatic animals* Based on the premise of investigating the actual situation and considering the food chain of the lake, we stocked 80 000 silver carp and bighead carp as well as about 50 000 mussels, snails, and other similar animals. The benefits include increased plankton, improved biological community and biomass, and improved capacity for removal of algae.

3.2.3 *Integrated floating island/simple floating bed* We have built several "integrated floating islands" at the following positions: in the center of the lake, at Wangjiawan pollution stations, at Jihua Middle School, and at outfalls 1, 2, 3, and 4. Their specific design depends on local conditions within the lake. The total area of these artificial floating islands is about 6 000 m^2. We planted aquatic plants such as water cabbage and water spinach on the floating islands, and we hung mussels, snails and other aquatic animals from the bottom of them. The design intent is that they be useful and sustainable.

In the remainder of the main bay, we laid some simple floating beds along the edge of the lake, each having an area of about 4 000 m^2. The intent is that nutrients in the lake could be removed by the absorption capacity of the aquatic plants. The benefits of combining aquatic plants and aquatic animals is that nutrients are removed more effectively from the lake and this reduces the amount of algae in the water,

thereby purifying it. Aquatic plants can be salvaged and recycled on land regularly. In this way the nutrients in the lake get absorbed through the removal of aquatic plants from the floating islands and beds.

3.2.4 *Artificial wetland technology* Four artificial wetlands were constructed according to the conditions created by the main rainwater inflows into the lake. Water percolates through these wetlands, each of which has an area of 1 000 ~ 1 500 m^2. "Windmill grass" (*Cyperus alternifolius*) was selected as the principal wetland plant. The benefits of this approach include improving the purification of rainwater runoff and sewage, and erecting a screen to protect the lake. In addition, the wetlands provide efficient removal of phosphorus and are self-maintaining. They also add to the diversity of the landscape features of Shuanglong Lake.

3.2.5 *Ecological filter ditch* We have created an "eco-block" near the sewage and storm water outfall where the urban sewage pipe network is difficult to access. The length of this ecological filter-ditch is about 1 000 m; the width and depth are both 0.5 m. We established wetland plants on both sides of the ditch. The wetland plants are mainly windmill grass. The bottom of the ditch is laid with stones, activated carbon, sand, and other substances which act as adsorbants. The benefits are reduction of pollutants entering the lake and cleaner water in the lake.

3.3 Post-regulatory measures

For most lakes, input of external nutrients are the the root causes of eutrophication. In order to control the eutrophication of Shuanglong Lake fundamentally, we implemented the lake interception project, including intercepting and treating sewage, as well as diverting sewage and rainwater. We also implemented ecological restoration and reconstruction of the lakeside landscape, as described above. Post-regulatory measures include the following: (1) strict enforcement actions against the re-emission of pollutants; (2) strengthening the daily care of wetlands and banks; (3) strengthening the surface and lakeside cleaning of the lake by removing litter; (4) no barber, car wash, and other waste water permitted to directly enter the lake; (5) forbidding agricultural land reclamation near the lake; (6) opening the lake moderately to recreation and strengthening environmental management of water-related entertainment; (7) strengthening the monitoring of water quality; (8) enacting contingency plans for algal blooms; (9) wide use of propaganda and calls for public participation.

4 Effect of the *in Situ* Restoration Project

The water quality of Shuanglong Lake had been at or near Class Ⅴ before management (Tab. 1), and the main pollutants were *TN* and *TP*. After management, as Tab. 2 shows, *TN* and *TP* content in the water were significantly reduced, and the water quality had been improved up to Class Ⅲ in 2011. The water quality is continuing to improve.

Tab. 2 Water quality monitoring results of Shuanglong Lake after management mg · L^{-1}

Section	Time	Water quality	Index	COD_{Cr}	NH_3-N_r	TN_r	TP_r
Dyke	2011 10.8	Ⅲ	Data	15.37	0.085	0.818	0.043
			Level	Ⅲ	Ⅰ	Ⅲ	Ⅲ
Jinghu garden	2011 10.8	Ⅲ	Data	15.18	0.079	0.83	0.049
			Level	Ⅲ	Ⅰ	Ⅲ	Ⅲ
Middle of lake	2011 10.8	Ⅲ	Data	13.25	0.153	0.977	0.022
			Level	Ⅱ	Ⅱ	Ⅲ	Ⅱ

5 Conclusion

The *in situ* restoration project of Shuanglong Lake has made full use of bottom dredging, aquatic stocking, integrated floating islands, artificial wetlands and various other advantageous techniques and methods that have been optimally combined and synthetically managed. The practice proved that *in situ* restoration of an urban lake in its original position not only saves resources and energy, but also realizes consistent, per-

manent, and efficient consequences, compared to other more traditional physical, chemical, biological and position-shifting methods. This approach will not only be consistent with an ecological approach to city construction, but will also help to clean and beautify the city environment and provide a reference point for urban lake management at home and abroad.

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(Editors: Martin WILLISON, YOU Zhong-sheng)
(English Translator: GUO Xiang)