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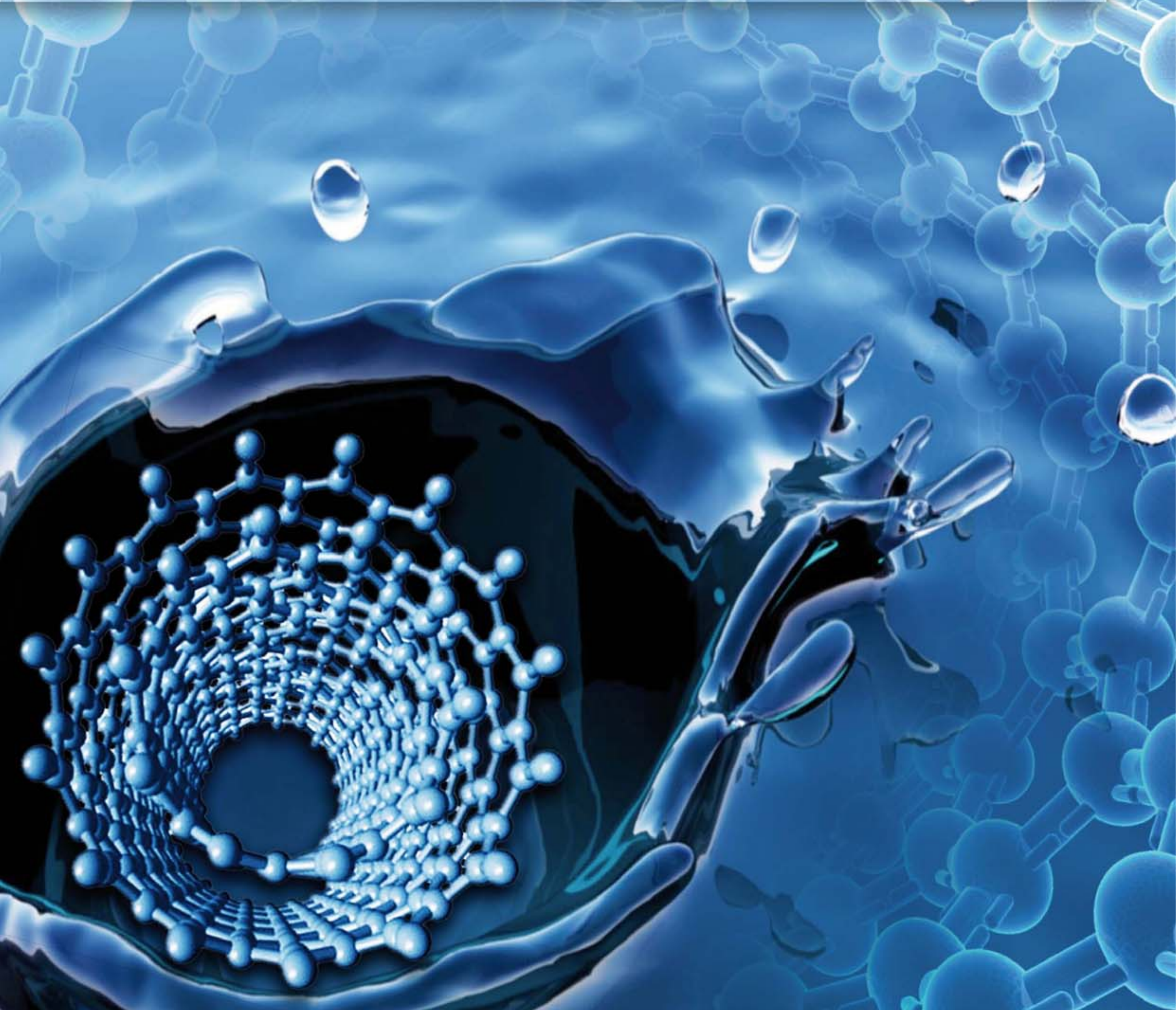

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Rehabilitation and improvement of Guilin urban water environment: Function-oriented management

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Abstract

Economic development and population growth have deeply damaged the urban water environment of Guilin City, China. Main problems involved structural damage and functional deterioration of the urban waters. An integrated technical scheme was developed to rehabilitate the urban water environment and to enhance the waters' functions during 1998–2008. Improvement of waters' functions included water system reconstruction, water pollution control, water safety assurance, and aquatic ecological restoration. The water system was reconstructed to connect different waters and clean water supplies to the lakes. Moreover, water pollution was controlled to improve water quality by endogenous pollutant elimination and extraneous pollutant interception. In addition, ecological measures put in place serve to enhance water system functions and better benefit both nature and humans. The project has brought about sound ecological, economic and social benefits in Guilin City, which can potentially be extended to similar cities.

Key words: urban water environment; ecological engineering; hydrology connectivity; landscape reconstruction; vegetation buffer strips; water conservancy

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Introduction

Urban water systems to a large extent have been appropriated directly for human use or affected indirectly by human activities (Postel, 2002). In the 20th century, human activities associated with urban development permanently altered natural waters hydrology, geomorphology, water quality, and ecology from their original states (Levell and Chang, 2008; Moglia et al., 2012). It is well understood that, although the return to a pristine condition is not possible for many urban waters, the potential scope for recovery is still large.

Brookes and Shields (1996) considered that if natural hydrology and morphology were recreated, with careful consideration given to hydraulic aspects, there was a high possibility that natural ecological recovery would follow. On the contrary, Ormerod (2004) argued that ecology stood alongside an array of crucial disciplines in restoration science among which none should take precedence: geomorphology, hydrology, hydrochemistry, engineering and socio-economic sciences. Practical restoration of urban waters is a very complex task largely due to the interactions between the physical, chemical, and biological components (Freeman et al., 2007). Therefore, restoration should encourage collaboration among investigators from multiple disciplines (Gosselin, 2008; Krozer et al., 2010).

Because humans dominate urban ecosystems, integration of social, behavioural, and economic research would be a proper approach to restoration (Walsh et al., 2005; Tullos et al., 2009). An understanding of the various factors influencing urban waters' condition and potential rehabilitation options is essential to determine the process and measures successfully (Findlay and Taylor, 2006). Operational measures are needed to treat human interference and ecological stress when urban waters are maintained and rehabilitated (Booth et al., 2004; Sanon et al., 2012).

Urbanized waters pose particular challenges for management given their inherent changing nature (Rai, 2011). This work demonstrated an integrated technical program for rehabilitation and enhancement of the urban waters' functions by way of correlated engineering measures in Guilin City, China. The physical, chemical and biological problems were determined. Correspondingly, engineering measures related to waters connections, water purification and ecological restoration were carried out. The addressed projects resulted in sound ecological, economic and social

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benefits.

1 Problems and strategy

Located in the northeastern part of Guangxi Zhuang Autonomous Region, Guilin City covers an area of 4195 km^2 and has a population of 1.2 million. It has a southern subtropical monsoon climate, with an average annual temperature of 19.1°C and an annual rainfall of 1890 mm. Guilin is a key tourist city of well-known culture and history in China. Numerous caves and residual hills have been formed from the dissolution of extensive outcrops of limestone and dolostone. With typical karst characteristic, the urban water system is highly sensitive to environmental stressors as well as temperature, climate, hydrology, vegetation, geology and the carbon cycle (Zhang et al., 2005).

1.1 Main problems

The Li River passes through the city, of which the Peach River is the main confluent running through the city (**Fig. 1**). Shan Lake, Rong Lake and Gui Lake are located in the city. Yet there was the fourth lake, Mulong Lake, nearby the Tiefou Pond in the Song Dynasty, which connected the urban inner lakes to the Li River. During a long historical period, human activity had made the ancient lake disappear. Not only did natural water shrink, but also connections between the lakes and the rivers were broken. Flooding and waterlogging threatened urban inhabitants and their properties.

A total of 17% of municipal wastewater directly discharged into the lakes before 1998, which resulted in serious water pollution. Runoff with urban non-point source pollutants freely flowed into the lakes. A perennial sludge deposit over 1.5 m thick on the lakebeds generated harmful gases with offensive odor, under anaerobic conditions. Water in the lakes was worse than Grade V of the Chinese Environmental Quality Standards for Surface Water (CEQSSW) (GB3838-2002), in particular containing excessive nutritive salts, e.g., ammonium salt and phosphate. Such nutrients caused serious eutrophication in the lakes.

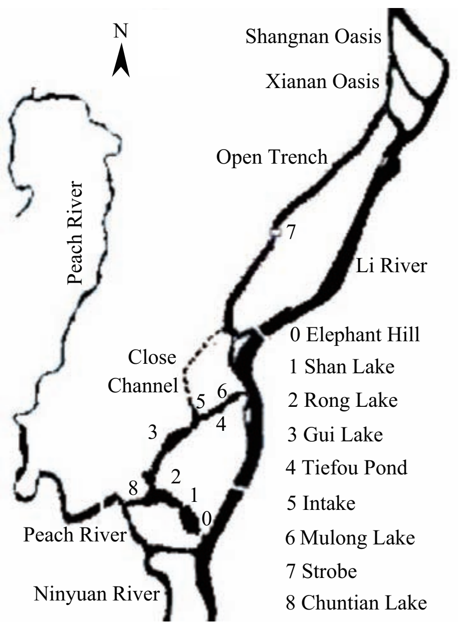

Fig. 1 Present pattern of the urban water system.

A direct consequence of the physical destruction and chemical degradation of the lakes was degeneration of the urban ecological system. Biological species decreased in the urban waters due to lack of protection. Low biodiversity created vulnerable aquatic and terrestrial ecosystems. Only 30% large woody vegetation covered the riparian zone while few aquatic plants lived in the lakes and the rivers. Only 4–8 kinds of fish could survive, which was only equal to 20%–30% of the fish in the upstream of the Li River. Amphibians hardly appeared around the lakes. Urbanization together with intense human activities resulted in extreme biological deficiency in the lakes.

1.2 Rehabilitation scheme

A rehabilitation scheme was devised to revive the natural water system, which focused on enhancement of functions in the water system. The plan and design considered human elements with respect to the habitat-based and watershed process-oriented factors. An integrated program mainly relied on urban hydraulic engineering, through which ecological ideas penetrated the project (**Fig. 2**). Urban hydraulic engineering fundamentally served regeneration of the waters while environmental engineering contributed to improvement of water environment quality. Rehabilitation of the water system with enhanced functions may be ultimately beneficial to the ecological, the social and the economic aspects.

A rehabilitation scheme for guiding rivers and lakes project was proposed (**Fig. 2**). The water system was first reconstructed to connect different waters and clean water supplies to the lakes. Moreover, water pollution was controlled to improve water quality by endogenous pollutant elimination and extraneous pollutant interception. Flood control and waterlog prevention provide safety to the urban area. In addition, ecological measures serve enhancement of water system functions and better benefit to both nature and human.

2 Water system reconstruction

2.1 Water system connection

Reconstruction of the fourth lake, Mulong Lake, not only connected the inner lakes with the rivers, but also reproduced the pattern of the ancient water system (**Fig. 3**). Geological explorations and hydrogeologic tests showed that the thickness of the soil layer averaged between 10–12

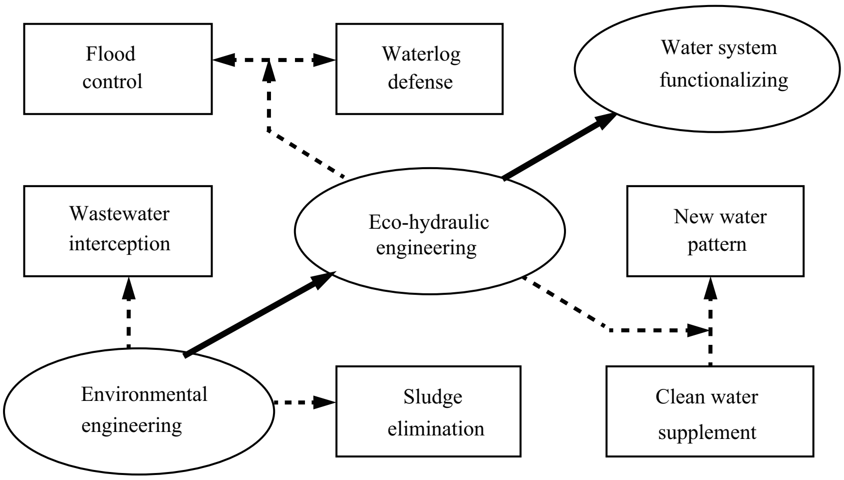

Fig. 2 Rehabilitation scheme of the water system.

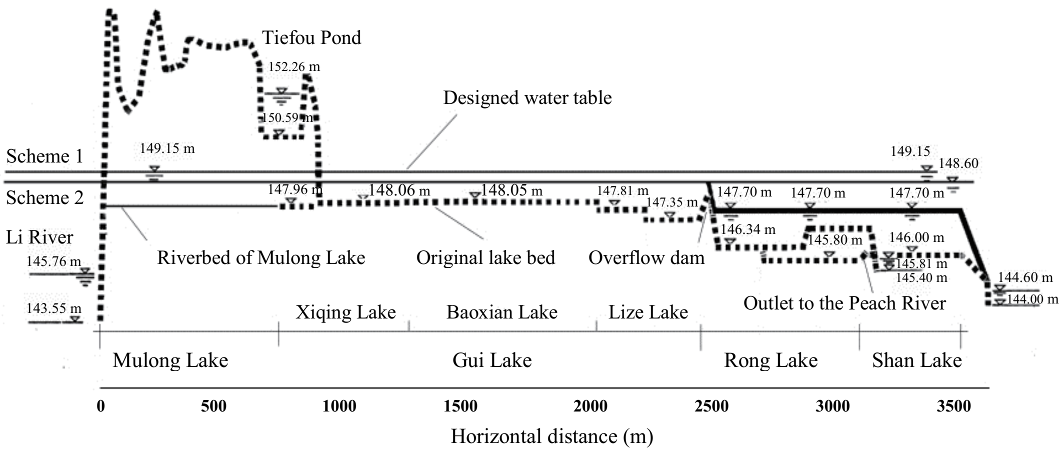

Fig. 3 Water level linkages and waters connection.

m above the impermeable rock layer. Over 5 m low-permeability red clay soil was beneath the lake. The area of the new Mulong Lake reached 5000 m^2. The water levels of the lakes were evenly linked at 149.15 m (Scheme 1 in **Fig. 3**). Together with other works of water connection engineering, the excavated earthwork was 500,000 m^3 and the volume of the lakes reached 782,400 m^3.

2.2 Water transport

Clean water was transported from Shangnan Oasis in the upper stream of the Li River to Gui Lake (**Fig. 1**). A two-in-one pipeline was designed to inhibit water pollution during the transportation route and ensured that clean water was supplied to the lakes. A new closed concrete channel was built along the existing open trench to transport water into the lakes, while the open trench only served agricultural purposes on the route. Along the transportation of 7331.6 m, the constructed channel was 3941.6 m long and 8 m wide. The mean flow was designed to 1.35 m^3/sec. The water regeneration period was on average 6.71 days in the lakes (**Table 1**). This remarkable improvement of the self-purification capacity can assure water quality in the lakes.

3 Water pollution control

3.1 Elimination of endogenous pollutants

Accumulated sludge in the lakes was on average 1.5 m thick (except Mulong Lake) before the rivers and lakes project. An inverse siphon technique and long-distance sludge transportation were successfully applied to achieve elimination of sludge on the lakebeds (**Fig. 4a**). The techniques minimized harm to the aquatic ecological system with better inhabitant protection during the engineering period. In practice, a total of 600,000 m^3 sludge was pumped to a dumping site, 8 km away from the lakes,

Table 1 Water volumes and exchange periods of the lakes

Lake	Volume ($\times10^4$ m^3)	Actual flow (m^3/sec)	Exchange period (day)
Mulong Lake	4.34	0.07	7.20
Gui Lake	24.34	1.28	2.20
Rong Lake	7.12	0.24	5.10
Shan Lake	42.45	1.04	7.00
Total/mean	78.24 (total)	1.35 (mean)	6.71 (mean)

within 6 months. The water quality of the lakes was greatly improved owing to reduction of endogenous pollutants.

3.2 Control of extraneous pollutants

A flow-division pipe system was designed and constructed to control extraneous pollutants by separation of rainwater and wastewater. Interception pipelines for wastewater from point sources pollutants and for rainwater with non-point sources pollutants were built around the lakes (**Fig. 4b**). About 20,000 tons/day intercepted municipal sewage was transported into the 4th Sewage Treatment Plant of Guilin, while rainwater indirectly flowed into the lower reach of the Li River.

In reference to the CEQSSW (GB3838-2002), the main water quality indices, i.e., suspended solids, turbidity, pH value, dissolved oxygen, permanganate demand, total nitrogen and total phosphorus, now meet the Grade III standard (**Table 2**). Sludge elimination and wastewater control improve the water quality of the lakes.

4 Functional rehabilitation

4.1 Flood control and waterlog defense

With the rise of the normal water level in the lakes after the waters' connection, flooding and waterlogging may threaten urban inhabitant safety. Two pump stations were assembled near Rong Lake and Spring Lake, which could defend against a 20-year reoccurrence flood and discharge surplus water from the lakes to the Peach River, as long as the water level in the river was no more than 148.5 m. The designed drainage rate was 12 m^3/sec. Nevertheless, when water levels of the rivers are higher than those of the lakes, two anti-flood valves at the diversion outlet of Shangnan oasis and the junction-point between the Mulong Lake and the Li River may be closed. In May and June, with 40%–50% of the annual precipitation, the water level of the lakes is limited to 148.95 m, and thus the added water volume in the lakes reaches 210,000 m^3, which could resist a 50-year reoccurrence flood.

4.2 Removal of barriers on the lakes

Before the rivers and lakes project, 8 old bridges were located on the lakes, whose bottoms were so close to the water surface as not to allow excursion vessels to pass through. These bridges were rebuilt to meet the requirements of waterborne tours, normally with freeboard of 2.8 m. The new bridges were also attractive scenery for the urban residents and tourists. Two ship elevators were installed, where one connects Mulong Lake to the Li River and the other links Spring Lake with the Peach River.

4.3 Ecological and economic benefits

Ecological measures were applied to rehabilitate the lakeshore. The ratio of large woody plants to total green coverage on average reached 42% with replanting of better vegetation (**Fig. 5a**). The density of aquatic plants increased due to self-reproduction in the high-quality aquatic ecosystem. Aquatic animals and amphibians grew in the habitats. The project has also resulted in sound economic benefit. Rehabilitation and improvement of the urban water environment have promoted the development of waterborne tours and visits to the historical site (**Fig. 5b**). Tourism contributes to the local economy by an additional 12.6 million CNY per year. The Chinese Ministry of Construction awarded the city "the most suitable city to live in China" in 2005.

5 Perspectives of function-oriented management

The urban water environment is typically sensitive to human activities, and its rehabilitation relies on function-oriented management (Moglia et al., 2012). The functions involve four aspects, i.e., water quantity, water quality, aquatic ecology and water landscape. In this work, the Guilin's urban water environment had encountered three-fold problems, which reduced the functions of urban waters. Water system reconstruction at first aimed at ensuring plentiful water and safe water supply for urban waters. Water pollution control moreover improved and

Table 2 Comparisons of water quality in the lakes before/after the project

Lake		Suspended solids (mg/L)	Turbidity	pH	Dissolved oxygen (mg/L)	Permanganate demand (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)
Mulong Lake	A	13	2	9.0	10.0	2.0	1.030	0.069
Gui Lake	B	23	30	7.7	4.2	8.3	7.60	0.377
	A	16	2	8.3	7.4	2.1	1.27	0.093
Western	B	15	20	7.6	2.4	6.5	9.15	0.369
Rong Lake	A	18	2	8.9	9.8	2.2	0.97	0.090
Eastern	B	9	15	7.6	2.3	5.6	8.38	0.326
Rong Lake	A	10	2	9.0	9.6	2.1	1.14	0.039
Shan Lake	B	12	8	7.6	2.4	5.3	7.42	0.329
	A	1	2	7.7	9.6	2.1	0.834	0.065
Grade III				6–9	5	6	1.0	0.2

A: after the rivers and lakes project project on May 22, 2005; B: before the rivers and lakes project on April 6, 1997; Grade III: from CEQSSW (GB3838-2002).

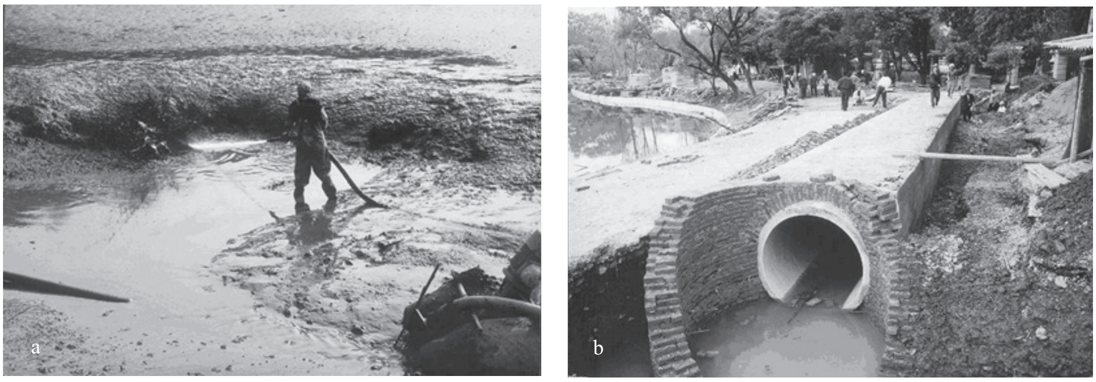

Fig. 4 Sludge elimination (a) and wastewater interception (b).

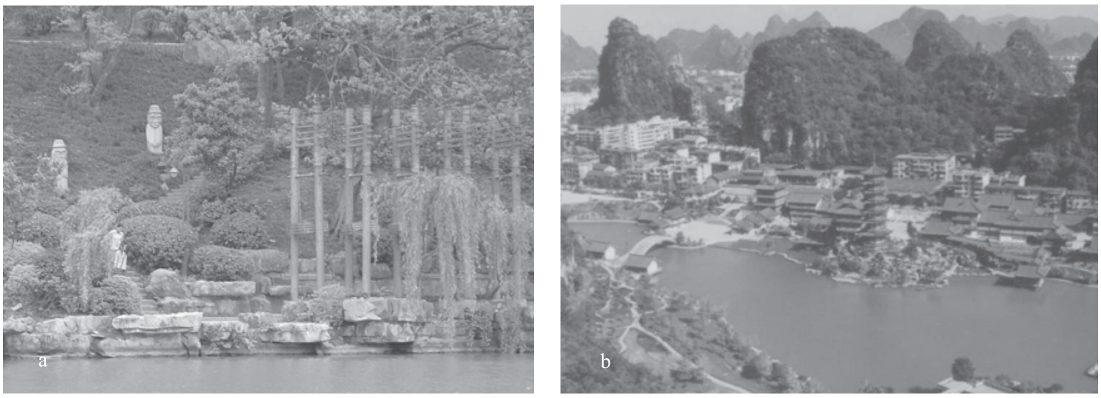

Fig. 5 Vegetation (a) and historical (b) site along the lakeshore.

maintained the healthful water quality in the lakes and the rivers. Then functional rehabilitation led to both beneficial aquatic ecology and a superb water landscape. Therefore, functional integration principally contributes to the improvement of the urban water environment (Sanon et al., 2012).

On the other hand, within the scheme of function-oriented management of the urban water environment, particular interests can be merged into the rehabilitation. Depending on the specific problems as well as their consequences, various functions may be considered and endowed with different weights (Krozer et al., 2010). The prime objective always concentrates on the key problem, for which the directed measure produces specific functions in the rehabilitation (Rai, 2011). Guilin is a tourism city, whose economic income mostly comes from tourism development. Accordingly, economic benefit, as a kind of function derived from the rehabilitation of the urban water environment, has been highly considered. The R&L Project has brought sound benefits to both the urban water environment and the urban residence with integrated consideration and particular interest placed on these functions.

6 Conclusions

Rehabilitation and improvement of the urban water environment have been coupled with the existing problems in Guilin City. An integrated technical scheme was developed both to rehabilitate the urban water environment and to enhance the waters' functions during 1998 to 2008. The function-oriented management consisted of water system reconstruction, water pollution control, water safety assurance, and aquatic ecological recovery. In practice, the restoration processes and achievements have been realized through comprehensive consideration of natural and humane benefits. Rehabilitation and improvement of the urban water environment with function-oriented management has brought about sound ecological, economic and social benefits in Guilin City, which can potentially be extended to similar cities.

Acknowledgments

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