DOI:10.15302/J-LAF-20170107
收稿时间 RECEIVED DATE / 2017-02-05
中图分类号 / TU986.2, Q14
文献标识码 / C

城市水体生态修复与景观的协同营建

COLLABORATIVE ESTABLISHMENT OF URBAN WATER ECOLOGICAL RESTORATION AND LANDSCAPE ARCHITECTURE

摘要

城市水系承担着提供水资源、发挥生态效应、承载城市生活等多种功能。通过城市水系设计能够优化水资源的时空分布，改善水文循环并提升水质，对城市生态系统而言有着重要意义。本文旨在探讨如何在最大限度地保护原有水生态系统的基础上，修复受损水生态，恢复城市水系综合功能，从而让城市弹性适应环境变化和自然灾害，同时提升水域周边土地价值与美学价值。作者从水陆交错带营建、水生生物的共生关系、水生生物栖息地营建等方面展开了讨论。

关键词

城市水体；生态修复；水系设计；景观设计

ABSTRACT

Urban water systems fulfill a variety of purposes, such as providing water resources, performing ecological functions, and supporting city life. The design of urban water systems optimizes the spatial and temporal distribution of water resources, improves the hydrographic circulation and water quality, bringing important influences to the urban ecosystem. This article aims to discuss how to maximize the protection of the original aquatic ecosystem, the repair of damaged water ecology, and the restoration of urban water system functions so as to endow the city with resilience to adapt to environmental changes and natural disasters, while enhancing the economic and aesthetic value of the land adjacent to water. A general discussion is provided on the establishment of water-land ecotones, symbiosis of aquatic organisms, and establishment of aquatic habitat.

KEY WORDS

Urban Water body; Ecological Restoration; Water System Design; Landscape Architecture

整理 涂先明
译 张健 阿梅莉亚 · 詹森
EDITED BY Xianming TU
TRANSLATED BY Angus ZHANG Amelia JENSEN

张饮江
上海海洋大学水域环境生态上海高校工程研究中心副主任、教授

Yinjiang ZHANG
Deputy Director and Professor of the Engineering Research Center of Universities in Shanghai for Water Environment and Ecology, Shanghai Ocean University

李凤莹
上海海洋大学硕士研究生

Fengying LI
Master Student of Shanghai Ocean University

吴文明
上海中汇水生态科技有限公司工程师

Wenming WU
Engineer of Shanghai Zhonghui Water Ecological Technology Co., Ltd.

引言

水是生命之源、生产之要、生态之基，是人类文明与城市文明产生及发展的先决条件之一，是人居环境最主要的组成部分。城市水系承担着提供水资源、发挥生态效应、承载城市生活等多种功能。通过城市水系设计能够优化水资源的时空分布，改善水文循环并提升水质，对城市生态系统而言有着重要意义；水生态系统在一定程度上决定了城市的可持续发展水平，决定了城市应对自然灾害的能力。健康的水环境是城市可持续发展的重要保障。

随着社会经济快速发展，人民生活水平提高，工农业废水和生活污水排放量逐年增加，城市水资源短缺、径流污染、河湖污染等问题日益严重，水系功能被片面化和简单化，水系失去了作为城市生态廊道的基本条件，严重威胁着居民健康和生态安全，制约了城市的可持续发展。

本文旨在探讨如何在最大限度地保护原有水生态系统的基础上，修复受损水生态，恢复城市水系综合功能，从而让城市弹性适应环境变化和自然灾害，同时提升水域周边土地价值与美学价值，构建具有地域特色的景观，满足人们对水体景观的感官需求。

水体生态修复与景观的协同营建

城市水体生态修复设计主要运用地理信息系统的空间分析技术手段，综合考虑城市水体生态受损与退化程度、城市气候特征、地势地貌、生物类型，以及相关的流域条件，分析城市水系的景观格局、生态过程和人类活动的相互作用，从而划定不同等级的水体生态修复区，确定水体功能与水环境容量。并与城市规划有机协调，将灰色基础设施与绿色基础设施协同整合，同时将环境工程技术、景观工程技术及经济社会调控措施相结合，通过控源截污，对水体形态结构、生物多样性、水量水质与雨洪管理等方面进行综合规划设计。

水陆交错带营建

水陆交错带连通水体生态系统和陆地生态系统，也是二者能量流、养分流、物种流的汇集之地，具有稳定流域生化循环、过滤器屏障、防洪消浪、生境栖息、护岸稳定等作用。在城市水体水陆交错带的营建中，应根据城市水系水流方向与河岸生态及安全特征，在完善沿岸截污管网的基础上，保持河岸生态系统合理的内部结构和良好的生态功能，以恢复水陆交错带景观的自净功能。同时，在适宜地段建立多样化岸坡景观，并营造亲水的公共空间。

根据水生植物的不同生态位，由陆生植物、湿生植物、挺水植物、浮水植物所构建的水陆交错带，可有效阻滞地表径流、净化水质、过滤面源污染，并为水生动物提供栖息空间。近自然的曲折岸线，可以营造出水流时空上快与慢、深与浅、陡与缓的变化，丰富岸边生物栖息地，保持水体生物多样性。而硬质驳岸往往会削弱水陆交错带的生态功能。在必须采用硬质驳岸的地带，也可以利用蔓藤植物覆盖硬质驳岸，以达到软化驳岸的生态效应。

水生生物的共生关系

因地制宜地构建水生生物物种的配置结构、时空结构和营养结构，使各物种互利共生，形成丰富的食物链，从而发挥水体的生态功能和景观功能。

在城市水体的生态修复中，要科学合理地设计植物群落，并改善微生物生长的条件，同时根据水生动物生态生理特性对其进行配置，使水系中形成合理稳定的水生物种群结构，各种群生物量和生物密度达到均衡，以实现有效的物质循环与能量流动。通过定量投放及捕捞鱼、虾、蟹、贝等动物，让水中的氮、磷通过在不同营养级中转移来抑制水体富营养化。例如设计一定数量的滤食性鱼类（鲢鱼、鳙鱼）和底栖动物（河蚬、蚌、螺等）可以对水体中浮游生物进行有效控制。通过人工调控水体中的土著微生物，提高微生物的有效生物量和效率，来分解污染物，促使水体生态系统恢复自净能力，形成适宜多种水生植物和水生动物生存的栖息地，提高生物多样性，防治生物入侵，促进水体生态系统的稳定性。

在构建“水生植物-底栖动物-鱼类-微

生物”共生的高效复合生态净化系统的同时，还可以配置水生态系统敏感性指示生物，以便及时且直观地反映水体污染与水生态综合状况，建立水体生态系统健康评价预警系统。

水生生物栖息地营建

生物多样性的基础是栖息地的多样性，水生生物栖息地的营建有利于提高生物多样性，并促进其发挥自净作用。因此，在水系空间规划中不仅要重视水系格局，保障水系畅通，保留河床滩涂，还应重视水系与城市整体景观格局之间的关系，避免栖息地破碎化。由水位涨落造就的滩涂湿地景观，也是维持水体生命健康的关键。

营造深浅不一、陡缓相异的水系，以及湖岛河滩、复合湿地、水上森林、水下森林等有利于形成丰富的水生生物及鸟类栖息地，从而营造立体的生态景观。并通过跌水、喷泉景观，对水域曝气复氧，提高水体中的溶氧量，恢复水体中好氧生物的活力，使水体自净能力增强，从而改善水系水质与景观状况。

城市水体的河湖床通常采用“锅底状”形态，形成深水与浅水区，并营造不同形式的深槽–浅滩序列环境，设计“鱼道”结构，形成鱼类洄游道路，从而塑造不同栖息地，为水生生物提供生长空间。

底泥是水体污染内源因素之一，底泥中的有机物在细菌作用下分解，会降低水中的溶氧量，并产生硫化氢、磷化氢等恶臭气体，使河水变黑变臭。定期进行生态疏浚，可有效减少水体内源污染，为底栖动物、沉水植物的恢复创造条件。

水中物材的筛选

在生态驳岸的填石区，可利用沸石和石灰石作为景观载体，利用其吸附氨氮与磷的特性，水流的波动会促进沸石系统微生物膜的更新和形成，达到去除水中氨氮的目标。并可利用农业废弃物、水生植物，集成多种脱氮技术构建的生物质碳源型生态浮床系统来改善水质，以及借助喷泉型浮床系统——利用太阳能的喷泉浮体，通过设计调控与藻类生长密切相关的限制因子，例如改变入射水中光谱——来抑制藻类生长，从而改善水质。

水污染削减与利用

城市水系健康的基础在于拥有清洁的水资源，城市水系受污程度不同、污染物来源及水体纳污能力也不完全相同，因此截污分流、从源头治理是城市水系生态修复的重要方法之一。

我们需要因地制宜地设计封堵、截流、防倒灌等综合措施：对各类污水排水口及雨污合流管口进行“控源截污”，并发挥景观功能化、功能景观化的协同作用来对污水资源化利用，对雨水、中水进行回收利用。以与城市污水处理厂相结合的复合湿地为例，其通过科学控制湿地水动力过程，促进硝化与反硝化作用，降低污染物浓度，可有效阻止污水处理厂尾水直接汇入河流。

结语

水是城市发展的重要自然资源、经济资源、社会资源和生态资源。城市水系设计应跨越学术领域和知识范畴，将生态与环境、城市与自然、规划与设计等学科交叉整合，将科学、艺术、工程、技术进行跨界整合，将水利环保、城建绿化、农业渔业、旅游、建筑与景观设计跨行业优化整合，从而实现水资源、水环境、水生态、水安全、水文化与水景观的协同发展。LAF

Introduction

Water is the source of life, the key to production, the base of ecology, one of the prerequisites of human and urban civilization, and one of the most important components of the human settlement. Urban water systems fulfill a variety of purposes, such as providing water resources, performing ecological functions, and supporting city life. The design of urban water systems optimizes the spatial and temporal distribution of water resources, improves the hydrographic circulation and water quality, bringing important influences to the urban ecosystem. The quality of the ecological water system, to a certain extent, determines a city's level of sustainable development and its ability to withstand natural disasters. A healthy water environment is an important guarantee of sustainable urban development.

With the rapid development of social economy and improvement of living standards, wastewater and sanitary sewage from industry and agriculture have been increasing year after year. Urban water shortages, runoff pollution, river and lake pollution, and other issues have become increasingly serious, making the function of the water system simplified and specialized. The basic conditions of the urban ecological corridor have been lost, which seriously threatens residents' health and ecological security, and has become an important factor restricting the sustainable development of the city.

This article aims to discuss how to maximize the protection of the original aquatic ecosystem, the repair of damaged water ecology, and the restoration of urban water system functions so as to endow the city with resilience to adapt to environmental changes and natural disasters, while enhancing the economic aesthetic value of the land adjacent to water, and building water landscapes rich in regional characteristics that meet the recreational needs of people.

Collaborative Establishment of Water Ecological Restoration and Landscape Architecture

In the design of urban water ecological restoration, the spatial analysis technology of GIS is used to consider the damage and degeneration of urban water ecology, urban climate characteristics, topography, biological types, and related drainage conditions, as well as to analyze the relationships between human activities, landscape patterns, and the ecological processes of urban water systems. This analysis helps to define different levels of water ecological restoration areas, and to determine the functions of different water bodies and their water environment capacity. Urban water ecological restoration design integrates gray infrastructure and green infrastructure. In conformity with environmental engineering technology, landscape engineering technology, and economic and social regulation and control, and through the control of water sources and interception of wastewater, this process conducts comprehensive planning and design in aspects including water form and structure, biodiversity, water quality and quantity, and rainwater management.

Establishment of Water-Land Ecotones

The water-land ecotone is the confluence of energy, nutrient, and species flows which connect the water ecosystem and the terrestrial ecosystem. Its various functions include stabilization of biochemical cycles, filtration barrier, flood control, habitat, and bank protection and stabilization. Urban water-land ecotones should be established according to the direction of river flow and river bank ecology characteristics. First, the network of riparian sewage interception pipes should be improved, and a satisfactory internal structure and ecological function of the riparian ecosystem should be maintained, so as to restore the self-purification function of the water-land ecotone. In appropriate zones, diversified riverside landscapes can be established, and hydrophilic public spaces created.

According to the unique ecological niche of aquatic plants, water-land ecotones should be established with terrestrial plants, wet plants, emergent plants, and floating plants which can effectively block surface runoff, improve water quality, filter non-point source pollution, and provide habitat space for aquatic animals. The natural zigzag bank line creates variations in the flow of water — fast and slow, deep and shallow, steep and gentle — which helps to maintain the riparian habitat and water biodiversity. Hardened shorelines, by contrast, tend to weaken the ecological function of the water-land ecotone. In areas where hard shorelines must be used, the shoreline can be covered with creeping plants in order to achieve the landscape effect of softening the shoreline.

Symbiosis of Aquatic Organisms

Urban water restoration design should establish structures of distribution, time and space, and nutrition for aquatic species, build mutual benefits and symbiosis among species, and form a rich food chain, so as to help the water body perform its ecological and landscape functions.

In the ecological restoration of urban water, we should scientifically and rationally design the plant communities, improve the microbial growth conditions, rationalize and stabilize the population structure of the aquatic biology, and balance the nutrients of the biomass and density, in order to achieve effective material circulation and energy flow. Through introducing or capturing fish, shrimp, crab, shellfish, and other animals in certain amounts, we can transfer nitrogen and phosphorus to different trophic levels, and thus control water eutrophication. For example, a certain number of filter-feeding fish (silver carp, bighead carp) and benthic animals (Corbicula fluminea, clams, snails, etc.) can effectively control the amount of plankton in the water. Through artificial regulation of the indigenous microorganisms in the water, we can improve the effective biomass and efficiency of microorganisms, decompose pollutants, improve the self-purification ability of the water ecosystem, create habitat suitable for a variety of aquatic plants and animals, improve biodiversity, prevent biological invasion, and promote the stability of the water ecosystem.

While establishing the highly efficient, symbiotic, and ecological purification system for aquatic plants, benthonic animals, fishes and microorganism, we can also deploy organisms that act as water ecosystem sensitivity indicators. These indicator organisms promptly and intuitively reflect levels of water pollution and other aquatic ecological conditions, establishing a water ecosystem health assessment and early warning system.

Establishment of Aquatic Habitat

Biodiversity is based on habitat diversity, and the establishment of aquatic habitat can improve biodiversity and self-purification. Therefore, it is necessary to pay attention to the pattern of water systems, ensure water flow, and maintain riverbeds and mudflats in the spatial planning of water bodies. It is also necessary to pay attention to the relationship between water systems and landscape patterns, so as to avoid habitat fragmentation. The tidal wetlands created by water level fluctuation are also an essential factor of maintaining a healthy river.

The establishment of the deep or shallow, steep or gentle waters, the islands and flood land, the complex wetlands, swamps, and underwater forests, helps form rich habitats for aquatic organisms and birds, thus creating a comprehensive ecological landscape. Cascades and fountains aerate the waters, increasing the amount of dissolved oxygen and restoring the vitality of aerobic organisms. With enhanced water purification capacity, water quality and landscape conditions are improved as well.

In bowl-shaped urban riverbeds, the deep-water and shallow-water areas form a variety of conditions that support fish migration routes, providing diverse habitats and growth space for aquatic organisms.

Bottom mud is one of the endogenous contributors to water pollution — the organic matter in bottom mud is decomposed by bacteria, which reduces the dissolved oxygen in water and produces malodorous gases such as hydrogen sulfide and phosphine, making the river black and smelly. Regular ecological dredging can effectively reduce water pollution, and create conditions for the restoration of benthic animals and submerged plants.

Selection of Materials

In rock-fill areas of ecological shorelines, zeolite and limestone can be used as the foundation of the landscape. Their capacity for adsorption of ammonia nitrogen and phosphorus can be used to remove ammonia nitrogen from the water, as the water flow promotes the regeneration and formation of the biofilms for microbes in these systems. Agricultural waste materials and aquatic plants, integrated with denitrification technologies, can be used as carbon-storing biomass to build ecological floating bed systems that improve water quality. Another option is the fountain-type floating bed system, which uses solar energy and regulates limiting factors for algae growth, such as changing the incoming water spectrum, to inhibit algae growth and improve water quality.

Reduction and Utilization of Water Pollution

A healthy urban water system depends on clean water resources. Due to varying levels of pollution, pollutant sources, and water pollution capacity, the interception of pollution at its source is one of the most important methods of urban water system ecological restoration.

A variety of infrastructures can be designed to block, intercept, and prevent polluted water by controlling pollution sources, intercepting the wastewater of various types of sewage drainage and combined sewer systems, dealing with sewage, and recycling and reclaiming water. Take the integrated constructed wetland of the municipal sewage treatment plant as an example — by controlling the hydrodynamic process of the wetland scientifically, simultaneous nitrification-denitrification can be promoted and pollutant concentrations reduced, therefore effectively preventing the tailwater from the sewage treatment plant from draining directly into the river.

Conclusion

Water is an important natural, economic, social, and ecological resource for urban development. The design of urban water systems should step across academic domains and knowledge areas to integrate ecology and environment, city and nature, planning and design through the interdisciplinary methodologies of science, art, engineering, and technology, involving the fields of water conservancy, urban greening, agriculture, fisheries, tourism, architecture, and landscape architecture. In this way, we will be able to realize the collaborative development of water resources, water environments, water ecology, water security, water culture, and water landscapes, and comprehensively improve environmental quality. LAF