城市河道“近自然化”修复案例研究与启示

The Case Study of "Close-to-Nature" Restoration of Urban Rivers & Enlightenment

雷泽鑫 杨冬冬 曹 磊

LEI Zexin, YANG Dongdong, CAO Lei

雷泽鑫 / 1993 年生 / 女 / 风景园林学博士在读 / 研究方向为城市景观水文与生态工程、海绵城市建设

LEI Zexin，female，was born in 1993. She is the Ph.D. in Landscape Architecture, School of Architecture in Tianjin University. Research directions: urban landscape hydrology and eco-engineering, sponge city construction.

杨冬冬 / 1985 年生 / 女 / 清华大学景观学系博士后 / 天津大学讲师 / 研究方向为城市水环境生态修复、海绵城市建设

通讯作者邮箱（Corresponding author Email）：ydongdong0308@163.com

YANG Dongdong, female, was born in 1985. She is the postdoctoral candidate, Department of Landscape Sciences in Tsinghua University, and the lecturer in Tianjin University. Research directions: ecological restoration of urban water environment and sponge city construction.

曹磊 / 1962 年生 / 男 / 博士 / 天津大学建筑学院教授、博导 / 研究方向为区域及城市景观的文脉延续和生态可持续研究

CAO Lei, male, was born in 1962. He is the Ph.D., Professor and doctoral Supervisor, School of Architecture in Tianjin University. Research directions: context continuation and ecological sustainability of regional and urban landscapes.

摘要：城市河道渠化对河流生态系统造成胁迫，导致城市河流环境进一步恶化。由于当前众多的城市河道治理实践并没有实现其生态系统良性循环，故而虽然投入大、成本高、技术手段日趋复杂，但治理效果并不理想。本文结合国外河流生态修复与改造案例，从设计到施工两个层面解读“近自然化”的河道修复理念，以期不断更新河流治理的策略和技术，为我国河流生态修复实践提供新思路。

关键词：城市河流；生态修复；渠化河道；河流近自然化修复；风景园林

Abstract: The channelization of urban rivers may cause stress on the river ecosystem and further deteriorate the surrounding environment. Because of the failure in realizing a virtuous cycle of

ecosystem in the decontamination process, generally the treatment of urban rivers does not achieve the desired results despite of huge investment, high cost incurred therefore and application of advanced technology. Hence, it is necessary to broaden the scope of our ideas and methods, and renew our tactics and technology in treatment of urban rivers. Based on the cases of ecological restoration of urban rivers in other countries, the paper interprets the “close-to-nature" concept of river treatment from the perspective of design and construction, in order to provide a new insight for the practice in China.
Key words: urban river; ecological restoration; channelized river; close-to-nature renovation of river; landscape garden

引言

当今，中国对城市生态建设的要求不断提升。水环境治理作为生态文明建设的主要途径之一，受到普遍重视。在政策方面，2017 年住建部推出“城市双修”，其目的之一即是致力城市河流等城市生态的自我修复；2018 年习近平总书记在《打好决胜全面建成小康社会三大攻坚战》中，明确提出水体环境治理是标志性重大战役之一。在投资方面，2018 年我国 36 个重点城市直接用于黑臭水体整治的投资累计 1140 余亿元；2019 年雄安新区水源上游的定州水生态修复项目总额逾 30 亿元。

城市河流作为城市发展的命脉，也是城市水系统的重要组成部分，不仅承担着行洪排水等基本功能，而且在城市生态化建设中至关重要。因此城市河流生态的修复与重建对于城市系统的和谐运作、城市的可持续发展和满足人们的生活需求都具有重要意义[1]。

1 我国城市河道整治的现状

1.1 城市河道的症结

在我国河道治理方面的政策扶持和资金支持下，目前全国范围内的河道整治工作迅速展开。如上海市投入 140 余亿元，用 10 年时间完成三期苏州河环境综合整治工程。此外，各类新技术如生态调水方法、新型浮床护坡材料、新能源复氧曝气技术和生物水质净化工艺等也在探索中应用，为净化河道水质、改善环境发挥了一定作用。

但是，综合耗资大、养护难、不可持续等河道治理的现实问题，让城市河道的长期治理成效并不理想。归其原因，主要有两个：一是被动式实现水体流动性。河流通过机械做功“获得水动力、完成水循环、治理水污染”。这种模式虽在短时间内实现了河流水体循环，但此过程需要大量人力财力，故而难以持续。由此说明，只有还原水体的自然流动属性，恢复其原本的理化性质，才能改善河流的健康水平，提高水体的自净能力，实现长效治理。二是河流的“开放性”没有全面、实质性恢复。常见的外源引水模式虽可短时、足量补水，人为抬高水位，但断裂的“河流内部-周边环境”相交织的生物链未能得到有效修补，导致河流水生侧和陆生侧无法实现物质循环、能量流动和信息交流，使得河流生态系统难以动态平衡。

城市河道的生态修复应是一个缓慢而长久的过程。上海市在苏州河治理中所投入的大量

时间、人力和财力，在其他城市中是难以复制的。因此，在我国河道治理步入生态环境综合治理的阶段，需要从健康自然河流的生态状况中探索规律与方法，引导河流生态系统自修复，实现人与河流的和谐相处。

1.2 城市河道生态修复的方向

国外研究越来越关注河道形态和地貌过程在生态系统健康和恢复工作的持久性方面所起的作用[2]。对于城市河流而言，渠化是城市对于其自然属性最大的改变。这种均一化的渠道形态对河流生态系统造成胁迫[3]。《人民日报》曾从批判的角度指出，“一些地方出现了很多貌似正确、实际上却埋下隐患的‘伪生态’行为。比如，全面‘硬化’‘渠化’河道，让水土分离、水与生物分离，粗暴地阻断了河道与岸线的生态功能”[4]。渠化是现代城市河流不可避免的症结所在[5]。

近年来，“海绵城市”倡导的“低影响开发”理念和“自然做功”策略给我国城市河道修复带来新启发。保证城市雨洪安全的前提下，适当改变河流形态，诱导河流生境自恢复，可促进河流生态系统良性发展。“近自然化”的修复策略不仅是国内外河流保护恢复重点，也是海绵城市建设的重要一环。本文将结合国外河流生态修复案例，从设计和施工两个层面，解读“近自然化”理念下的城市河流生态修复方法。

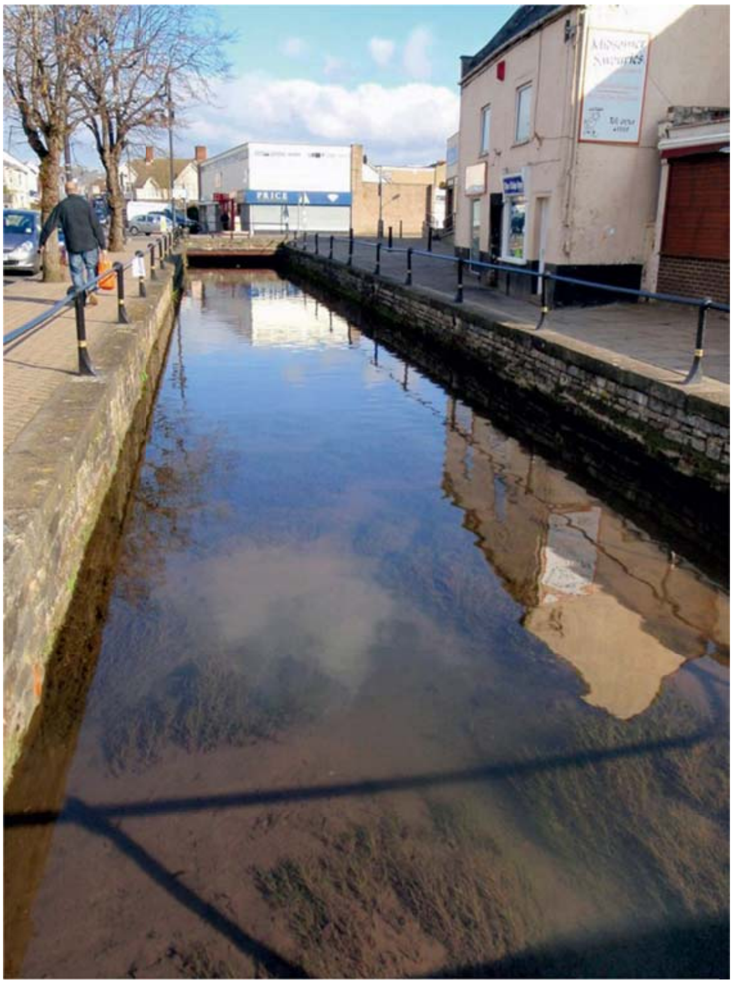

图 1 修复前纵坡较缓，水流不畅

Figure 1 The River Slope is Slow and the Water Flow is Not Smooth Before Restoration

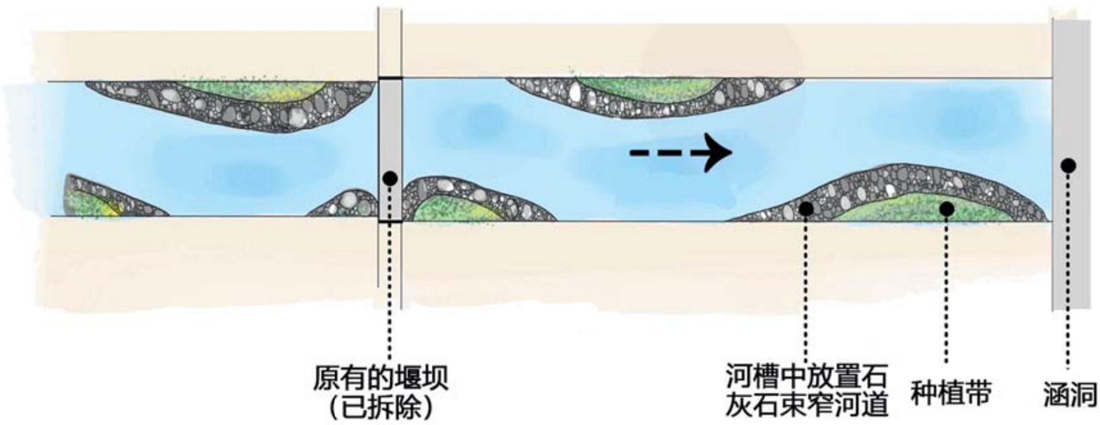

图 2 修复策略说明

Figure 2 River Restoration Strategy

图 3 修复后的河流生态多样性

Figure 3 River Biodiversity after Restoration

2 “近自然化”的城市河流生态修复设计方法

河道渠化造成城市河流形态的均一化，具体表现为河道纵向的布局直线化、横断面的规则几何化和河床材料的硬质化。在城市中，对渠化河道进行生态修复具有一定难度。首先，受限的城市用地没有足够空间来还原河流的曲折形态；其次作为城市防洪排涝的重要通道，受两岸堤坝束缚也难以获得缓冲空间；最后，大规模拆除现有硬化护岸，不仅耗资大、难实行，而且拆除工程产生的大量建筑废弃垃圾会造成环境的二次污染。

与我国类似，欧美等国的诸多城市中也存有大量为了保证行洪安全而被全线硬化的渠化河道。上世纪 50 年代，德国提出“近自然河道治理工程”，要求仿照健康自然河流的生境特点，使改造后的河流得以植物化和生命化(Laubetal，2009)。“近自然化”河流修复理念发展至今，在欧美国家的应用日渐普及，也形成了相对成熟的河流生态修复实践技术，尤其在城市、城郊二、三级河道的使用中取得了很好的效果。本文通过研究这些案例，探讨城市渠化河道的“近自然化”生态修复方法。

2.1 案例介绍

2.1.1 英格兰萨默塞特郡萨默河修复案例[6]

英格兰萨默塞特郡的萨默河因河道纵坡较缓且沿线设有阻水堰，造成水流不畅、淤堵严重（图 1）。针对该问题，相关人士提出近自然化的岸坡处理技术：束窄河道，提高流速，增加河道内的自然生境空间（图 2）。整体操作分为四个部分：首先，将阻水堰整体拆除的同时，保留两侧的结构，其目的是在严重干旱的时候可以安装临时隔板蓄水保持水深；然后，用当地石灰岩堆置于河岸内缘，打破原有的直线式沟渠，束窄河道且增加曲折；同时，用石头堆砌代替原来的小型堰坝，以增加整个河道水深；最后，将椰壳填塞于石灰岩堆中，在河道两岸形成蜿蜒的边缘种植带。修复前的河段平均水深 0.5 m，河道平均宽度 4.5 m。治理后的萨默河主河槽宽度减少一半，水深降低 0.1 m。在治理后的一年时间里，尽管发生了几次洪水事件，但护堤完好无损，河道沿线未受影响。

萨默河虽受现状条件约束，无法打破现有硬化的线性边界，但在低流量主河槽中塑造的蜿蜒通道增加了河道宽度和深度的变化性，提高了水流多样性，为鸟类、哺乳动物和无脊椎动物提供适宜栖息地（图 3）。

2.1.2 英格兰西南端康沃尔郡瓦伦西河修复案例[6]

英格兰西南端的康沃尔郡瓦伦西河渠化后河流比降大、河道距离短，容易造成沿岸水土流失，同时给下游地区带来雨洪风险。相关人士主要通过两项措施来平衡比降、降低雨洪风险、改善河流生境（图 4）：第一，通过切割原有的陡直坡岸，适当拓宽河道，来提高河道防洪能力。由于河道两岸的石质护坡具有较强的层理面，沿着边坡方向有明显裂缝线，可以将石质护岸沿着切割成锯齿状，锯齿一侧垂直于裂缝线，另一侧倾斜向下（图 5）。在起伏不平的石质护坡形成的凹槽内利用淤泥固定乡土湿生植物，减缓水流和沉积砂石，形成河岸生境。第二，在适当的河床位置挖深或铺砌石块，从而将原来接近 1:45 的纵坡比降为坡度较缓的阶梯层级式（图 6）。随着较高强度的水流冲刷，石质护坡崩裂下的碎石沉积在河床，一方面使得固坡形态更加自然稳固，另一方面，这些碎石沉积于河道中形成碎石浅滩，丰富了生境多样性。

瓦伦西河针对渠化河道问题，通过低成本的方式适当拓宽河槽、平衡比降，减缓河道高

落差大流量，改善河道生境。不仅利用当地石质河床的自然特征，实现了河道的适当拓宽；而且利用改造后的河岸种植植物阻碍水体，降低流速。利用河岸切割的石块和当地石材改变河床的形态，将陡坡变缓，塑造了多样的河道生境和丰富的河道植被群落。

2.1.3 英国爱丁堡市布雷河英奇公园段修复案例[6]

英国爱丁堡市的城市砖砌河道——布雷河贯穿英奇公园的北部边缘。英奇公园是爱丁堡市重要的生物多样性保护区，为了提高河流的蓄洪能力，公园在改建时重新设计了河道路径（图 7）。公园将 80 %的传统沟渠形态改为蜿蜒自然式。河道修建所产生的土方石块回收用于填充旧河道，减少施工垃圾，节约建设成本。公园选用椰壳纤维编织的生态材料作为新河道的边坡护岸，保证固土护坡的同时，实现了水陆两侧物质能量相互渗透交换。在公园改建一年后，椰壳纤维编织材料逐渐被沉积的泥沙覆盖。随着人工植物的种植，生态边坡渐渐形成滨水植物群落，进而形成新的湿地生境。监测发现河道中出现了水獭等新的“居民”。

布雷河贯穿城市绿地的现状优势，为河流形态改变提供可利用的有效空间。蜿蜒的河道形成了细沟、浅滩、深潭、弯道等不同宽度和深度的多样形态。河流形态的多样性促进了河流的自然发育过程和生态过程，形成了多种动植物栖息地，有利于生物多样性。

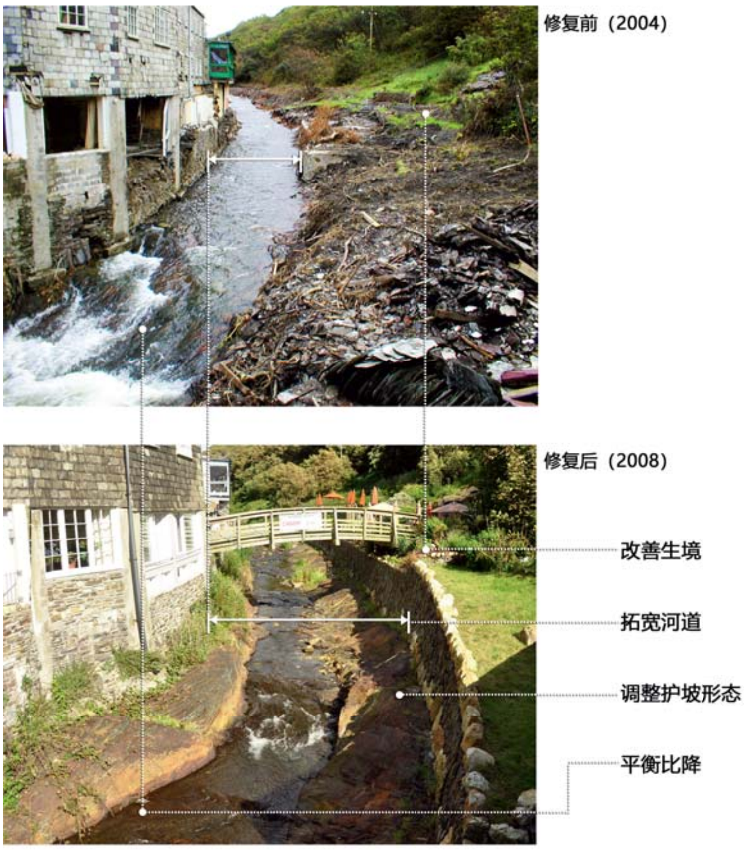

图 4 河道修复策略

Figure 4 River Restoration Strategy

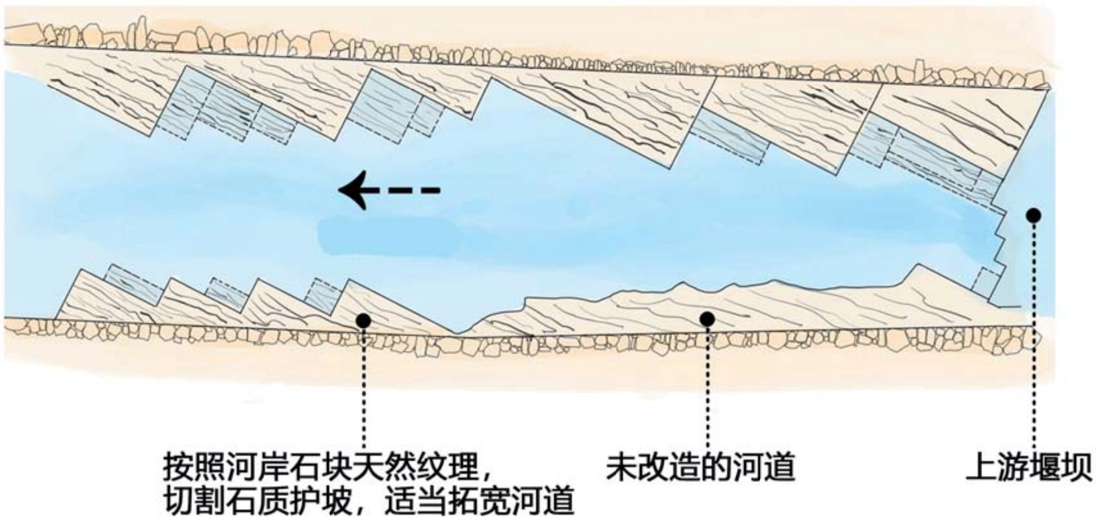

图 5 切割后形成的护岸平面

Figure 5 The Plan of Slope Revetment after Restoration

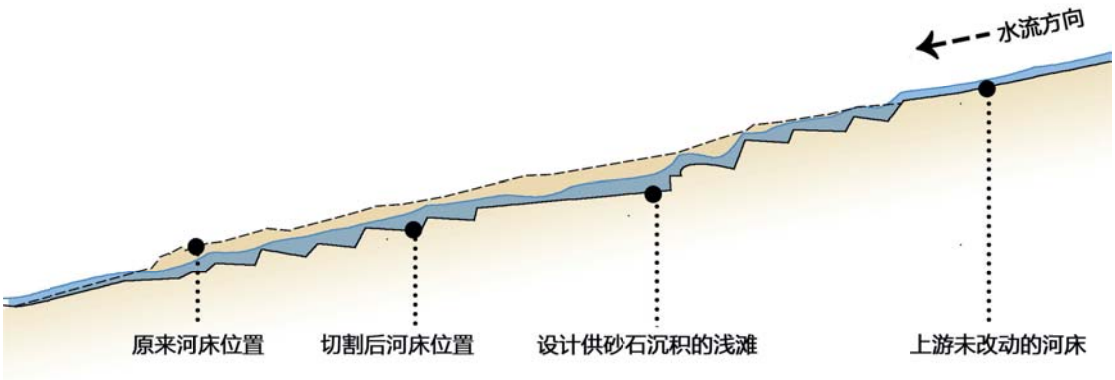

图 6 深挖后形成的河床纵剖面

Figure 6 The Longitudinal Section of the River Bed After Restoration

2.2 启示

河流保护和恢复必须考虑河道的形态变化及其带来的生态变化[7]。事实证明，通过诱发渠化河道水流自驱动，不仅为雨水径流实现了更有利的缓冲空间，而且可以有效修复城市河道生态。面对城市河道简单僵化的现状，上述案例可给出以下启示：

2.2.1 改变形态均一性

顺直的渠道并不是河道的天然形态。保持河流的蜿蜒性是保护河流形态多样性的重点[8]。打破城市渠化河道的形态均一性，是城市河道生态修复的第一步。这并不意味着河流的彻底自然化。在城市河道有限空间内，适当恢复河流的自发动态能有效提高河水的流动性。如河

道毗邻城市绿地或非生产性用地，则是城市河道生态修复较为理想的环境条件。这些空间可为“河水的流通涨落提供一定程度的自由范围”[9]。可借鉴布雷河的做法，适当改变河道线性布局，还原蜿蜒形态，扩展滨水空间，提高承载力。但城市用地较为紧张，河流通常鲜有可利用的外部空间。萨默河通过在陡直河道边缘砾石堆叠束窄河宽，营造蜿蜒形态，不仅有效提高水流流速，而且营造了河水-砂石河岸的自然生境空间，同时不影响河道泄洪功能。如仍有一定范围的弹性空间，则可参考瓦伦西河通过切割石质河槽，将河道试适当拓宽或加深，增加蓄水空间，营造自然式水景观。

2.2.2 增加通道复杂性

适当增加通道的复杂性，增大水流与边坡的摩擦，有利于水流中泥沙的沉积。具有适当泥沙运输沉积的动态河道更有可能支持复杂通道形态[10]。打破河流形态单一化的设计前提下，增加河流空间复杂性，提高水流空间质量，为动植物创造多样生境，是城市河道生态修复的第二步。

河道纵向布局形态的改变，对应到河流的横断面即是水流通道的复杂化。三个案例通过多种方法来丰富河流横断面：萨默河通过在河槽中置堆石块、填充淤泥、附着植物，形成近自然式的河道横断面；瓦伦西河通过人为切割和堆砌石块，形成模拟自然状态的“急流-深潭”水阶梯；布雷河通过在绿地范围内适当拓宽部分河道，营造出浅滩、曲湾、细流和沼泽等多种生境形态。

2.2.3 提高水陆连通度

城市河道边坡软化，不是要求将所有的硬质边岸拆除，而是使用透水的自然材料进行河道护坡，实现近自然化的河道生态修复。在我国的河流生态修复中，广泛使用植草砖、种植格浮体和模块式绿化等人工材料实现边坡绿化。但是，这种护岸绿化不仅人工痕迹较重，而且并未恢复河道生境。以上三个案例均是使用当地生产或就近获得的石材、植物来重塑河道生境。通过生境营建和低干扰的管理方式来引导水陆连通，实现生态系统的循环。此外，利用天然材料不仅工程成本低廉，而且操作难度低，同时实现了工程垃圾零排放。

3“近自然化”的城市河流生态修复施工方式

施工过程不是简单地“制造结果”，而应该是温和地“设计过程”。A.M.Gurnell 等通过对欧洲的 143 条城市化河段研究得出结论，较少的工程干涉有利于实现河道生态多样性、栖息地连接性和植被结构多元化[11]。一方面，长时间、慢动作、低影响的动作力度，能够有效减少施工动作对于河流生态的二次干扰。另一方面，各方力量协作配合下的设计施工，才能真正实现河流的适地性生态修复。

3.1 施工时长：长时间+慢动作+低影响

英格兰希灵顿地区巴宾利河[6]的生态修复工程中，为了避免对鱼类通行产生障碍，降低对鱼类产卵的影响，施工分步分批地安装和拆除截留挡板。两至三周为一个拆卸周期，导致并不烦琐的施工三个月才完成。此外，由于施工缓慢，有效减少了水流冲刷，促进了淤泥的沉积。植被在新暴露出来的淤泥中生长，帮助巩固淤泥，创造新的栖息地。该项工程完工不

久后，已经有鱼类和无脊椎动物的生存，证明了施工过程的低干扰。

这种长时间和慢动作的施工，有效降低了工程对于河流的影响，为河流创造了一个自适应和调节的过程。该方法的一大优点就是施工过程与河流的自然过程相结合，为河流的生态修复创设了一个维持相对稳定的环境。

3.2 施工模式：专家现场指导 + 技术工人操作 + 多方民众参与

施工现场情况复杂多变，河流生态修复工程并不能完全实现按照图纸施工的理想状态。解决意外状况更多的要依靠多方人员的协调配合。如对于瓦伦西河石质护岸的切割和对河床的重塑，是由河流工程师现场指导工匠操作完成。此外，公众参与是城市河流生态治理、恢复与管理的重要方式。如萨默河是由工匠、设计师、志愿者与社区居民共同完成。萨默河之友组织的志愿者负责清除河道内的垃圾和有害物种。社区居民参与设计施工以及河道生境的后期维护（图 8）。2011 年项目完成后，该河道获得当地议会颁发的环境改善市民“最自豪的地方”奖。

4 结语

城市渠化河流的生态修复面临河流形态单一、河流兼具多重功能、修复空间狭小受限等多重问题。传统治理方法成本高、投入大、干扰强，并不利于实现河道的长效治理。

本文从河流生态修复的设计和施工两个层面，解读国外河流生态修复的“近自然化”实践案例。面对城市渠化河道，可根据能够利用的修复空间尺度，适当改变河道的均一化形态。在形态改变的基础上，运用生态材料，增加通道复杂性、提高水陆连通度。通过多方人员协调配合，以温和的施工模式，引导河流实现在修复过程和修复目标两个层面的“近自然化”。

图 7 英奇公园修复前后河道形态对比示意

Figure 7 Comparison of River Morphology Before and After Restoration

图 8 附近居民参与河道修复

Figure 8 Community Participation in River Restoration

Introduction

China attaches great importance to the treatment of river pollution in the urban area in recent years, and has made a lot of investment in this regard.For example, China has continuously raised its requirements for ecological construction. As an important part of the ecosystem, water environment is in the spotlight lately. In terms of policy, the "Double Urban Restoration" initiative proposed by the Ministry of Housing and Urban-Rural Development in 2017 is committed to restoring the self-regulating function of urban rivers and other ecosystems. Improving the water environment is one of the targets of the "Three Campaigns on Building a Well-off Society in an All-round Way" proposed by General Secretary Xi in 2018. The 36 key cities in China invested more than 114 billion Yuan directly in the treatment of odorous water in 2018. In 2019, Beijing invested over 3 billion Yuan in the Dingzhou water ecological restoration project, which is upstream of the river system which provides drinkable water to Xiong'an New Area, the new sub-center of Beijing.

As the life line of urban development, as well as the important part of the municipal water system, urban rivers not only assume the basic function of flood drainage in the urban area, but also play an indispensable role in construction of an urban ecology. Therefore, ecological restoration of urban rivers is of great significance to harmonious operation of the urban system, the sustainable development of the urban area, as well as meeting the need of the people's life.

1 Current Situation of Urban River Management in China

1.1 Major Issues

Thanks to the preferential policies and financial support from the government, management of urban rivers in China may achieve quick results because of better operability. For example, Shanghai invested more than 14 billion Yuan in 10 years for the third stage of Suzhou River ecological restoration project. And attempts at use of new technologies, such as ecological water transfer, new floating bed materials for revetment protection, new energy reoxygenation & aeration technology and biological water purification technology, play a role in the purification of river environment.

However, because of a host of issues, such as the huge cost incurred, the difficulty in maintenance, as well as unsustainable treatment methods, the ecological restoration of urban rivers does not meet the desired results in the long term. There are two main reasons: (1). Passive realization of water mobility. The "hydrodynamic force, water circulation and water pollution control" of rivers are realized through mechanical work. This model can realize the circulation of river water in a short time, but it consumes a lot of manpower and material resources. Hence the unsustainability. Only by restoring the physical and chemical properties of urban rivers, as well as its natural flowing properties can the rivers' self-purification capacity be restored and long-term treatment realized. (2). There is no comprehensive and substantial recovery in the "openness" of urban rivers. Although the commonly-used external water diversion mode can replenish water in a short period of time and artificially raise the water level, the biological chain which is interwoven with the broken "river interior and surrounding environment" is not effectively repaired, which may lead to the failure of material circulation, energy flow and information exchange between the aquatic side and the terrestrial side of the river, thus resulting in the difficulty of realizing a dynamic balance in the river ecosystem.

Ecological restoration of urban rivers is a slow and long-term process. For example, Shanghai invested a lot of human and financial resources and spent a lot of time in decontaminating Suzhou River. And it is difficult for other cities to replicate the practice of Shanghai. Therefore, against the background that the water management in China is in a transition stage from specific river management to comprehensive ecological management, it is necessary for us to make new attempts from the perspective of guiding the self-restoration of river ecosystems and realize a harmonious coexistence between the human beings and urban rivers.

1.2 The Direction in Ecological Restoration of Urban Rivers

Foreign studies pay more attention to the role that the river morphology and geomorphic process play in restoring the ecosystem health and maintaining the sustainability [2].Channelization of urban rivers is the biggest change in a city's natural attributes. But homogenization of urban river morphology may cause stress on the river ecosystem [3]. From a critical standpoint, the People's Daily pointed out that "there are many 'pseudo-ecological' behaviors in some places, which seem to be correct but actually have hidden dangers. For instance, the overall hardening and channelization of the river channel may lead to separation of water and soil, as well as separation of water and biological elements, which roughly blocks the ecological function of the river channel between the water and the banks "[4]. Channelization is an inevitable issue in the treatment of modern urban rivers [5].

In recent years, the concept of "low-impact development" and the strategy of "natural work" advocated by the "sponge city" initiative have brought new inspirations to the management of urban rivers in China. Provided that the city is safe from rain and flood, the river morphology can be appropriately changed to induce the river's self-restoration capacity, which can promote the benign development of the river ecosystem. The "close-to-nature" strategy is the key to protection and ecological restoration of urban rivers at home and abroad, and it's also an important link in the construction of a sponge city. Based on the cases of ecological restoration of urban rivers in other countries, this article interprets the concept of “close-to-nature restoration” of urban rivers from the perspective of design and construction.

2 The Design of "Close-to-Nature Restoration” Method

Homogenization of river morphology includes straightening the river’s longitudinal layout, regularizing the geometry of the cross sections and hardening the riverbed materials. It is difficult to change the direction of urban rivers. Firstly, the limited urban land does not have enough space to restore the river to its meandering shape. Secondly, as an important flood control channel, the urban river bears the burden of diverting rainwater and flood. And it is difficult to expand the buffer space because of limitation by the banks on both sides. Finally, it is difficult to get financial support from the government if the hardened revetment is demolished. And moreover, it would lead to greater waste.

Similarly, many cities in Europe and the United States retain a large number of channelized rivers with slopes hardened by cement in order to ensure that they are safe from flood. The idea of "close-to-nature” river management proposed by Germany in the 1950s calls for application of ecological principles to change the traditional engineering methods so that the management of urban rivers conforms to the botanical and life principles (Laubetal, 2009). Up to now, the "close-tonature" restoration concept is more popular in European and American countries. And there are mature technologies for ecological restoration of small rivers in these countries. By studying these cases, this article discusses the effect of the "close-to-nature" design on the ecological restoration of channelized urban rivers in China.

2.1 Case Introduction

2.1.1 River Somer Ecological Restoration

River Somer in Somersetshire, England suffered from stagnant water flow and serious siltation due to the relatively gentle longitudinal slope of the river and the water blocking weir along the river (figure 1). In order to solve this problem, the "close-to-nature" slope treatment technology was used to narrow the river channel, speed up the water flow and increase the biological habitats in the river channel (figure 2). The overall operation divided into four parts. First, the weir was completely removed except for the structures on both sides. This is to install temporary partitions to store water and keep the water depth in case of severe drought. Then, the local limestone was piled on the inner edge of the bank to break the original layout of straight water course, narrow the river channel and create more twists and turns. The original small weir dam was replaced with stones to increase the water depth. Finally, coconut shells were packed in limestone piles to form a meandering edge which may be used as a planting belt on both sides of the river. The average water depth of the river before treatment was 0.5 m, and 4.5 m after. After treatment, the main channel of River Somer was reduced by half of the original width, and the water depth by 0.1m. In the wake of several floods within one year after the treatment, the revetment remained intact, and no there was no damage to the river channel.

Although River Somer does not break away from the existing hardened linear boundary due to the local conditions, the meandering course formed in the main channel where water flows slowly increases the channel’s variability in width and depth, which provides diversity for the water flow, as well as suitable habitats for birds, mammals and invertebrates (figure 3).

2.1.2 River Valency Ecological Restoration

After channelization, the River Valency in Cornwall, southwest England, had a steep gradient and a narrow channel, which was likely to cause soil erosion along the banks and bring rain and flood risks to the downstream areas. Two measures were mainly taken to ease the gradient, reduce the rain and flood risks, and improve the river's biological habitats (figure 4). Firstly, the river's flood control capacity was improved by chipping away the original steep slope and appropriately widening the river channel. The rocky revetment on both sides of the river has a strong plane of stratification and obvious crack lines along the side slope. The stone revetment is cut into serrations along the line, with one side perpendicular to the crack line and the other side inclined downward (figure 5). The native water-borne plants are fixed by silt in the grooves formed in the undulating rocky revetment to slow down water flow and deposit of sand, thus forming riparian habitats. Secondly, the original longitudinal slope which is close to 1:45 is reduced to a multistep gentle slope (figure 6) by digging deeper at appropriate portions into the river bed or paving stones on the riverbed. As result of the high-intensity scouring by water flow, the gravels generated by the cracking of the stone revetment are deposited on the riverbed. This promotes the natural stabilization of the revetment, and on the other hand, the gravels deposit in the river channel form gravel shoals, thus enriching the diversity of biological habitats.

As result of the channelization, River Valency appropriately broadens the channels, eases the gradient in a low-cost way and slows down the heavy water flow, thus improving the river's biological habitats. Besides appropriately widening the river channel by taking advantage of the natural characteristics of the local rocky riverbed, the approach also reduces water flow with plants planted on the renovated banks. Diversified biological habitats, such as rich vegetation communities are created along and in the river by using stones chipped away from the banks, as well as other local stones to change the riverbed, and by easing the steep slope.

2.1.3 Braid Burn Ecological Restoration[6]

Braid Burn, the brick ditches in Edinburgh, UK run through the northern edge of Inch Park. When renovating the park, important biodiversity conservation in Edinburgh, the engineers redesigned the path of the river flowing through the park to improve the river's flood storage capacity (figure 7). 80% of the traditional ditches flowing into the river were changed into naturally meandering forms. In order to reduce the ensuing construction waste and save the construction cost, the earth and stones generated from the newly excavated meandering rivers were refilled into the old river channel. Ecological materials woven from coconut shell fibers were selected as materials for revetment of the new river channel, which not only ensures soil stabilization on the revetment, but also realizes mutual infiltration, as well as exchange of materials and energy between the water and land. One year after renovation of the park, the coconut shell fabrics were gradually covered with deposited sediment in the river channel. With the plants planted on the banks, riparian plant communities gradually formed on the ecological slopes, thus forming new wetland biological habitats. New "residents", such as otters are found in the river.

Braid Burn flows through the urban green land, providing a space for effective change of the river morphology. The meandering river course results in various forms which have different widths and depths, such as rills, shoals, deep pools, bends, etc. The morphological diversity promotes the river’s natural development process and ecological process. The habitats for animals and plants are conducive to the development of biodiversity.

2.2 Enlightenment

In terms of protection and ecological restoration of urban rivers, it is necessary to take into account the rivers’ morphological changes and the possible ecological changes [7]. Facts have proved that inducing the self-driving capacity of channelized rivers may create a more favorable buffer space for rainwater runoff, and it can also effectively restore the urban river’s ecosystem. Given the simplified approach in treatment of urban rivers, the above-mentioned cases provide the following as an enlightenment:

2.2.1 Change the Uniformity of Morphology

Straight channels are not the natural form of urban rivers. Maintaining the meandering nature of urban rivers is the key to protecting the diversity of river morphology [8]. This is the first step to break away from the morphological uniformity in terms of ecological restoration of channelized urban rivers. However, it does not mean that the rivers will be completely natural. In the limited space of urban rivers, properly restoring the spontaneous dynamics can effectively improve the rivers’ fluidity.

An urban green space or unproductive land nearby may be an ideal environment for ecological restoration of the urban river. The space can provide "a certain degree of freedom for the water flow and fluctuation of the river" [9]. Based on the practice of Braid Burn, it is necessary to appropriately change the linear layout of the river channel within this range to restore it to a meandering shape, expand the waterfront space and improve the river’s bearing capacity. However, because of limited urban land, generally there is few extra space for ecological restoration of the urban river. In the case of River Somer, stones were piled on the edge of the steep banks to narrow the river and create a meandering shape. It not only effectively improves the water flow, but also creates natural biological habitats between the water and sandy banks. At the same time, it does not affect the river’s flood control capacity. If there was a flexible margin, River Valency would be appropriately widened or deepened in the main channel by dredging deeper into the rocky bottom to increase the space of water storage and create a natural water landscape.

2.2.2 Increase the Complexity of River Channel

It is conducive to deposition of sediment in the water flow by appropriately increasing the complexity of the river channel, as well as the friction between water and the revetments. A dynamic channel which is somewhat favorable for transport and deposition of sediment is more prone to the formation of a complex river channel [10]. Increasing the complexity of river channels, improving the quality of space for water flow and creating diversified biological habitats is the second step to break away from the simplified approach in the treatment of urban rivers.

Corresponding to the cross section of the river, changing the longitudinal layout of the river means that the flow channel would become more complicated. In the three cases above, various methods were used to enrich the cross section of the rivers. For example, a “close-to-nature” cross section was created in River Somer by stacking stones and filling silt in the river channel, and growing plants on the banks; River Valency created a multistep channel which features "rapids and deep pools" and simulates the natural state by chipping away the steep slopes and piling stones in the river channel; Braid Burn created diversified biological habitats, such as shoals, curved bays, streamlets and swamps by appropriately widening portions of the river channel within the green space.

2.2.3 Improve Connectivity between Land and Water

Softening the slopes of urban rivers does not mean demolishing the hardened portion of the banks, and instead, it uses natural permeable materials for revetment protection to realize the “close-to-nature” ecological restoration. In China, materials such as grass-planting bricks, floating plant grids and green modules are widely used for revetment protection. However, this approach has heavy artificial traces, and it cannot restore the natural biological habitats. In the three cases above, the biological habitats are created by using local or nearby stones or growing plants on the banks. Circulation of the ecosystem can also be realized by guiding the connection between land and water through the construction of biological habitats and low-interference management. In addition, utilization of natural materials not only reduces the construction cost, and it is less difficult in the practice, and at the same time, no construction waste ensues.

3 "Close-to-Nature" Construction Method for Ecological Restoration of Urban Rivers

The construction process is not a simple "manufacturing result", but a gentle "design process". A.M. Gurnell and others studied 143 urbanized river sections in Europe and concluded that less engineering interference is conducive to the realization of river ecological diversity, habitat connectivity and diversity of vegetation structures [11]. On the one hand, long-time, slow-motion and low-impact actions can effectively reduce the secondary interference of construction to the river ecosystem. On the other hand, the design and construction can truly realize the ecological restoration of rivers in suitable locations only with the cooperation of all parties.

3.1 Construction Period: Long Time, Slow Motion and Low Impact

In order to avoid any interference to the passage of fish and reduce the adverse impacts to the fish spawning in the vicinity, the River Babingley project [6] in Hillington, England alternated between installing barriers in the river channel and removing the barriers in a cycle of two or three weeks, which caused the uncomplicated project to last for three months. And as result of the slow construction process, the project effectively reduces the erosion of the river bed by the water flow, thus promoting the deposition of silt. Vegetation grows in newly exposed sludge, which is conducive to consolidating the sludge and creating new biological habitats. Shortly after the project, fish and invertebrates are found in the river, which is the proof of low interference in the construction process.

This long-time and slow-motion construction effectively reduces the impact to the river and creates a process of self-adaptation and adjustment by the river. One of the advantages of this method is that the construction combines with the natural process of the river to create a relatively stable environment for the ecological restoration of the river.

3.2 Construction Mode: On-Site Guidance by Experts, Technical Worker Operation and Multi-Party Participation

Since the ecological restoration of urban rivers is faced with complicated and changeable circumstances on the construction site, the project cannot proceed completely according to the drawings. Any unexpected issue should be solved through coordination and cooperation by the personnel involved. For example, in River Valency project, the cutting of stone revetments and reshaping of riverbeds were completed by construction workers under the guidance of engineers onsite. And public participation is also important. For example, the River Somer project was jointly completed by construction workers, volunteers and community residents. Volunteers from "Friends of the River Somer" participated in removing the garbage and harmful species from the river figure 8. In 2011, the residents living around the river were awarded "the proudest place" prize presented by the local council for environmental improvement.

4 Conclusion

Ecological restoration of channelized urban rivers is faced with a series of issues because the rivers are simple in form, but have multiple functions, and there is limited space for ecological restoration. The traditional mode of management, which is characterized by high cost, huge investment and strong implementation power, does benefit the long-term management of urban rivers.

Practice cases of river ecological restoration abroad are interpreted from two aspects of "design-construction" of river ecological restoration. It can be concluded that the ecological restoration of urban rivers can be completed in a moderate construction mode in a limited channelization space through human guidance. Design process: properly change the uniformity of the river channel shape, increase the complexity of the channel, and improve the water-land connectivity. Finally, the river will naturally do work after a certain period of time, thus realizing the "Near-Naturalization" of the urban river.

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（整理：赵迪 译：张悦颖）