对中国海绵城市建设再出发的若干问题反思
Reflections and Suggestions on China's Sponge City Construction

余年
SHE Nian

深圳大学建设工程生态技术研究所副所长、客座教授，美国环境工程师协会LID模型委员会主席、都市水资源研究委员会常委
Deputy Director and Visiting Professor, Institute of Construction Engineering Ecological Technology, Shenzhen University; Chairman of the Low Impact Development Modeling Committee and Member of the Standing Committee of the Urban Water Resources Research Council, American Society of Civil Engineers

谢映霞
XIE Yingxia

教授级高工，中国城镇供水排水协会副秘书长，中国城市规划设计研究院水务与工程院原副院长
Professor-Senior Engineer; Deputy Secretary-General of China Urban Water Association; Former Vice President of Institute of Water and Engineering, China Academy of Urban Planning and Design

李迪华*
LI Dihua

北京大学建筑与景观设计学院副教授
Associated Professor, College of Architecture and Landscape, Peking University

*通讯作者：
地址：北京海淀区颐和园路5号
邮编：100871
邮箱：dihuali@pku.edu.cn

编辑 | 周佳怡、田乐、冉玲于
翻译 | 田乐、周佳怡、申瑞琪、闫露
EDITED BY | ZHOU Jiayi, Tina TIAN, RAN Lingyu
TRANSLATED BY | Tina TIAN, ZHOU Jiayi, SHEN Ruiqi, YAN Lu

摘要

本文首先梳理了近几十年来中国水系统管理工作及海绵城市建设的发展历程。总体而言，呈现出工作目标由单一转向综合，行动缘起从问题导向转向研究和目标导向，评价指标从关注问题解决的数量向系统的绩效评估转变等特点。本文进而反思了中国自2015年推行海绵城市建设试点以来所引发的公众质疑的原因，并探讨了海绵城市建设所存在内涵解读、公众感知的绩效指标和施工质量等现状问题。作者借此指出，海绵城市作为城市水系统管理的综合手段之一，应当明确场地核心问题、目标和关键技术手段，提出针对性的、能够同时整合场地水相关问题和满足公众使用需求的解决方案。基于此，作者解析了进一步推进海绵城市建设工作的主要难点：1）统筹海绵城市建设与城市洪水风险管理的关系；2）建立海绵城市建设全过程的工程管理体系；3）明确主管部门、设计团队和施工单位的责任；4）转变认知和技术观念。与此同时，作者建议加强知识链接与人才培养，指出培养“专才”与“全才”的必要性。最后，强调了引入雨水收费等市场机制、优化现有政策和推进海绵城市建设常态化是未来水系统管理工作的重点议题。

关键词

海绵城市建设；城市水系统管理；雨洪；跨专业合作；人才培养；海绵城市建设常态化；政策；公众需求

ABSTRACT

This article first introduces the development of China's urban water system management and the Sponge City construction. Generally speaking, China's urban water system management has progressively turned into addressing water problems with integrated solutions, with the focus shifting from problem finding towards objective-setting and emphasizing theoretical significance. Meanwhile, the evaluation criterion has adopted more indicators valuing the quality and efficiency of projects' actual performance, rather than a rough quantitative measurement. Then this article addresses the potential reasons for the public questioning China's Sponge City construction since the implementation of pilot projects in 2015, such as the misunderstanding of its connotation, public perception of the projects' actual environmental performance, and construction quality. Only by recognizing the reality and identifying difficulties and primary goals, can the targeted and systematic solutions solving on-site water relevant problems and meeting public needs be proposed. In response, the authors put forward the major difficulties in future Sponge City construction promotion, which include 1) coordinating the Sponge City construction and urban storm water management to facilitate on-site runoff retention and address urban waterlogging problems; 2) establishing a whole-process management system for China's Sponge City construction projects that involves a series of stages; 3) identifying the accountability and responsibilities of the administration, design, and construction parties; and 4) updating knowledge and technical perception. Furthermore, the authors emphasized the importance of expertise collaboration and talent training to provide professionals with ability in practice, in-depth inter-professional and technical coordination, and active learning. Finally, the authors encouraged the key topics in the future—introduction of new market mechanisms such as storm water billing system, optimization of the current policy mechanism, and institutionalization of Sponge City construction.

KEYWORDS

Sponge City Construction; Urban Water System Management; Storm Water; Inter-professional Cooperation; Talent Training; Institutionalization of Sponge City Construction; Policies; Public Needs

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1 城市水系统管理的发展历程与海绵城市建设的诞生

过去几十年，水问题始终是中国的国家大事之一[1][2]。国家从始至终关注的一个核心水问题是水资源时空分布不均和水资源利用，因此而持续兴建了各种区域性水控制和大型调水等水利水电工程。随后，水安全（尤其是防洪排涝等问题）使得城市和区域水系统管理出现并成为水问题的工作焦点。此后，水污染问题及其对城市居民休闲游憩需求造成的影响引发关注，水污染环境治理和水景观建设的重要性被一再强调，城市成为水系统管理的重点对象。最后，湿地减少和生物多样性破坏问题逐渐显现，水生态修复在城市和区域都受到重视，不同尺度和规模的水生态修复工程层出不穷。伴随着实际工作和科学研究的逐渐深入，对水问题复杂性的认知更加清晰，水系统管理的目标也从单一转向综合——包括综合应对水资源、水利用、水安全、水环境、水生态和水文化等多元问题。这一过程与中国城镇化进程相伴相生，城市逐渐成为人居环境和水系统管理的主体，海绵城市建设亦酝酿并诞生于这样的时代背景下，雨洪最终成为城市水系统管理的焦点议题。[2]~[4]

2 海绵城市建设的核心目标与评价体系

水系统管理的目标是探索实现人地和谐的水问题综合性解决方案。围绕这个目标在城市中采取的所有措施——无论是雨污分流、溢流污染控制，还是水生态修复、水景观建设，抑或是海绵城市建设——都应当被视作手段。在未来的城市水系统管理工作中，不应再推行某些目标单一的工程措施，如修建单一功能的雨洪设施、不断改造污水处理厂和雨水管网等，而应按照城市雨洪管理专项化和常态化思路，结合海绵城市建设系统整合城市水系统管理的各项工作[1][2][4][5]。开展海绵城市建设，搞好城市水系统管理工作，首先应当识别实际问题和难点问题，搞清楚核心问题并确定核心目标，进而围绕核心目标提出系统化的解决方案。举例而言，若一个地区的海绵城市建设在设计阶段识别出的核心目标是尽可能地留住水（即雨水资源化），就应当系统探究水从哪里来、在何处及如何蓄积、净化等问题[6]。其他可能成为核心目标的还有湿地恢复、栖息地保育、季节性内涝、地下水位恢复、地表水质改善、水文化服务和水文化遗产保护等；核心目标可能不止一个，重点在于因地制宜，精准施策。[2][7][8]

1 The Development of Urban Water System Management and the Initiative of Sponge City Construction

Water problems has been one of China's main concerns over the decades[1][2]. From the beginning till now, China government has put a lot of effort into large-scale water conservancy and hydropower projects, such as regional water management and diversion projects, to optimize the distribution of water resources. In later years, China has also given a priority to water security issues, especially those concerning flood control and drainage, and established urban and regional water system management regimes. Then, to respond to the impact of water pollution problems on citizens' recreational opportunities, the government has paid attention to water body remediation, and underscored the importance of water landscape construction, with the focus of water system management shifting to urban areas. In recent years, the pressing wetland reduction and biodiversity loss made water ecological restoration emphasized at all scales. As the understanding of the complexity of water issues deepened in an evolving process of related practice and research, the goal of urban water system management has been progressively integrated, concerning water resources, water utilization, water security, water environment, water ecology, and water cultural services. Accompanied by China's urbanization, cities have become the main living environment and thus the main areas for water system management. Sponge City construction was also initiated in this context, and storm water issues eventually become a widely discussed subject in urban water system management.[2]~[4]

2 Primary Goals and Evaluation Criterion of Sponge City Construction

The aim of water system management is comprehensively address water issues to re-harmonize human land relationship, by means including rain and sewage diversion, overflow pollution control, water ecological restoration, water landscape construction, and, of course, Sponge City construction. In the future, instead of carrying out single-purpose storm water projects or repeated renovation of sewage treatment plants and drainage systems, all means should be integrated with Sponge City construction and enhance the specialization and institutionalization of urban storm water management[1][2][4][5]. In practice, only by recognizing the reality and identifying difficulties and primary goals, can the systematic solutions be proposed. For example, if increasing rainwater utilization (i.e. to retain and reuse rainwater) is identified as one of the primary goals in the design stage of a Sponge City construction project, it is fundamental to first find out where the runoff comes from, and where and how it can be accumulated and purified[6]—In other cases, the primary goal might be improving wetland restoration and habitat conservation, dealing with seasonal waterlogging, facilitating groundwater recharge and surface water purification, or enhancing water cultural services and heritage conservation. Differentiated measures should be adopted based on existing conditions.[2][7][8]

海绵城市建设工程应当以恢复健康的城市水文循环过程为主要目标，通过地形设计和海绵设施应用在不同尺度集水区系统组织径流，辅以宜人的人居环境建设要素，并据此设定相应的评价指标体系。早期城市水系统管理评价注重实际问题解决的“量”，如污水治理重点关注的评价指标之一——污水处理量占供水量的百分比。[9][10]由于各污水处理厂来水水质不同（因其水源可能包括河水、地下水等），往往会造成这一指标的虚高。过去常常出现某城市“污水处理率达90%以上”的说法，水污染问题却并未真正得到解决。现行评价体系以提质增效为目标，更加注重处理的实质效果，如引入“污水集中收集率”与“污水集中处理率”等指标以考察城市污水收集和处理系统的效率；在此评价标准下，全国实际的城市污水集中收集率比原指标数据要低很多。根据《“十四五”城镇污水处理及资源化利用发展规划》[11]，中国将力争在2025年使全国城市污水集中收集率达到70%以上。

经过多年海绵城市建设政策的推行，人们已基本认可了与灰色基础设施相结合的生态手段，接受了基于自然的解决方案是未来排水系统发展和水生态修复的主要趋势[12][13]，也意识到很多城市建设问题的症结在于大小排水系统整体规划的不完善。自2015年《水污染防治行动计划》公布以来，对于城市水系统管理，尤其是污水治理工作，从基本认识到绩效考核都已更加科学。[14]海绵城市建设评价体系在未来将更加综合、因地制宜，同时体现海绵城市建设问题导向、结果导向、目标导向和研究导向等特征。

3 海绵城市建设试点期间引发的公众质疑所揭示的问题

自2015年推行海绵城市建设试点工作以来，公众对海绵城市建设的质疑从未间断。一些公众无法切实体会到海绵设施的成效，究其原因，主要表现为三个方面。

首先是对海绵城市建设效果的期待过高，寄希望于通过一种方式解决所有水问题，一劳永逸。实际工作中却不可能存在这样的方法；加之某些海绵城市建设项目在前期宣传中夸大实施效果，无疑助推了公众误判。同样地，公众对海绵城市建设的工作性质理解也有所偏颇，认为源头减排设施就是海绵城市建设的全部。2014年出台的《海绵城市建设技术指南》[15]只是针对低影响开发设施而言的，根据此版指南，衡量海绵城市建设的指标是控制80%～85%场次降雨所产生的径流，就是通常所说的径流控制率，相对应的设计日降雨量是25～30mm左右。随着海绵城市建设的深入，其内涵已有了很大扩展。在各级区域与城市水系统管理工作中，除了现阶段以源头控制为主要手段的海绵城市建设以外，还包括区域尺度的水风险管理、水资源调度和城市尺度的雨洪管理（如水库调蓄及城市排水组织），它们应对的雨情各不相同。

公众质疑海绵城市建设的另一个原因是工程质量确实可能存在问题。公众只有在发生内涝时才会关心海绵城市建设工程，他们日常更加关心的是户外建成环境质量。海绵设施是否有效很大程度上取决于施工质量，这与公众对建成环境质量的感知特征是一致的。中国城市户外环境工程长期以来一直是施工导向，设计很多时候只是起辅助作用和服务

Overall, Sponge City construction projects should centered on the restoration of urban hydrological cycle with topographic design and application of sponge facilities to catchment runoff management at varied scales, secondary by the improvement of living environment and the development of corresponding evaluation criterion. In early years, evaluation criterion mainly covered quantitative indicators, including sewage treatment rate, which measures the percentage of treated sewage to the total water supply.[9][10] However, the indicator often saw false positives since the sewage source into each treatment plant varies (e.g. river water and groundwater)—This created the paradox that a city with a sewage treatment rate of over 90% but suffering from water pollution at the same time. The current evaluation criterion mainly value the quality and efficiency of projects' actual performance by indicators such as sewage concentrated collection and treatment rates, which will result in much lower values than before. According to the 14th Five-Year Plan for Urban Sewage Treatment and Resource Utilization[11], China will make sure a national urban sewage collection rate of over 70% by 2025.

The years of implementing Sponge City construction has demonstrated the working of ecological approaches combined with gray infrastructures, and make more and more people understand the potential of Nature-Based Solutions in holistic planning of drainage systems at all scales and water ecological restoration[12][13]. The launch of the Water Pollution Control Action Plan in 2015 promotes the public's awareness and professionals' scientific evaluation of urban water system management performance, especially in sewage treatment.[14] It is expected that in the future the evaluation criterion of Sponge City construction should adopt more indicators measuring the project's effectiveness in problem-finding, built-up performance, object setting, and research significance.

3 Public Doubts About Pilot Projects in Sponge City Construction

China's implementation of Sponge City construction pilot projects started in 2015 accompanies with the questioning of public who are not well aware of the benefits brought by these projects. The main reasons might be summarized in three aspects.

The first is the public's misunderstanding that Sponge City construction is an once-for-all means that addresses all water problems, which was somehow influenced by the over propaganda of projects' performance. It is also a biased understanding to equal Sponge City construction with building source reduction facilities. In the Sponge City Construction Technology Guidelines[15] issued in 2014, which targets more on low-impact development measures and mainly evaluates projects' performance in runoff control rate—it proposes a goal of on-site runoff control of most rainfall events, with a corresponding design rainfall about 25 ~ 30 mm/d. The connotation of Sponge City construction has been greatly expanded as the practice increases, covering water system management measures at varied scales, such as water risk management and water regulation at

于工程价格核算。目前，这种状况在海绵城市建设施工中并未发生实质性改变，“重施工、抢工期、轻设计”问题一直延续下来了。施工质量主要取决于现场工作人员的经验和态度，施工过程不规范、不严谨，施工水平低，加上工期过紧，一些源头减排的海绵设施建成后，工程质量粗糙情况长期被诟病。

海绵城市建设成长时间并不长，被质疑是推动海绵城市建设工作进步的必要成分和必经之路。海绵城市建设需注重全方位改善居民福祉，只有居民能够真正感受到城市水问题的解决，观察到生活环境质量改善，他们才可能更加支持建设者的工作，海绵城市建设自然就能由点及面地获得推广（图1，2）[16][17]。应该对30个海绵试点城市建设中公众关注的问题和各种针对性的解决方案进行整理，筛选出具备全面推广的技术措施；通过实地考察深入研究各海绵城市建设项目的施工质量标准及建设成效，为未来各地海绵城市建设的差异化目标及标准制定（排洪、截留及再利用、渗透等）提供数据支持与经验支撑，从而推动更多城市将海绵城市建设作为一个关键议题纳入到城市水系统管理工作中[18]。

海绵城市建设和所有规划与设计议题一样，存在抗解性问题（wicked problem）的特点[19]，发现和解决新问题的能力是必须面对的重要挑战。

4 进一步推进海绵城市建设工作的主要难点问题

经过专门设计的海绵城市雨洪系统镶嵌并叠加在各级水系统之中，一起构成整体的城市与区域、自然与社会水系统，目的是实现城市水系

1. 镇江华润新村改造项目中，海绵城市建设前后绿地和步道变化情况：建设前绿地高于路面，步道不可渗透，不利于排水（左图，中图）；右图展示了建设后的下沉式绿地及步道现状。
2. 在北京海淀畅春园小区改造项目中，通过将可滞留雨水的植草沟与专用步道结合设计，在减少内涝的同时改善了社区居民的步行环境。

1. The green spaces and footpaths before and after the Sponge City construction: before the renovation, the green space's elevation is higher than the path surface, and the impermeable pavement of footpath together make it difficult for on-site rainwater retention (left and middle); sunken green spaces and permeable pavement of footpath are used in the renovation.
2. In the renovation project of the Changchunyuan Neighbourhood in Haidian District, Beijing, the integrated design of bioswales and pedestrian pathways led to the waterlogging alleviation and improvement of residents' walking environment.

regional scale, and storm water management at city scale (e.g., reservoirs and urban drainage systems), to cope with different rainfall events.

Secondly, at present, the built-up quality of Sponge City construction projects may be inadequate. The public care more about the overall quality of urban built-up environment in their daily life, and only concern on the performance of Sponge City construction projects when floods or waterlogging events occur. The effectiveness of the projects' actual environmental performance is deeply affected by the construction. In China, urban outdoor environment engineering projects are construction-oriented, and the designers often play a subsidiary role. This is also true to the Sponge City construction, and there is a common idea of outweighing construction over design when facing with a limited project time span. In practice, a project's quality is largely determined by the on-site constructors' experience that often leads to substandard construction problems.

China's Sponge City construction is still in its exploratory stage, and the public doubts is inevitable but also important. People would change their awareness when they perceive and understand the various benefits brought by such projects including the mitigation of urban water problems and the improvement of living environment (Fig. 1, 2)[16][17]. Upon the public's concerns, professionals need to select effective techniques and measures from the pilot projects in 30 cities for a wider application throughout the country, and enhance data and experience collection to better inform the development of differentiated goals and evaluation criteria (flood discharge, interception and reuse, and infiltration, etc.) through in-depth studies on the construction standards and performance. These efforts will push forward the incorporation of Sponge City construction into urban water system management as one of the key objects in more cities[18].

Same as other planning and design subjects, Sponge City construction is of wicked problem[19] that requires professionals to improve their ability both in problem finding and solution making.

4 Major Difficulties in Future Sponge City Construction Promotion

The sustainable management of urban water system can be realized by establishing, embedding and overlaying wisely-designed storm water system of Sponge City into water systems across levels that establishes holistic systems at city




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统的可持续管理。进一步推进海绵城市建设工作，需要重点解决以下难点问题。

一是统筹海绵城市建设与城市洪水风险管理的关系。海绵城市建设作为城市雨洪管理的一个环节，其目标是经过海绵城市建设工程改造的城市集水区“小雨不积水，大雨不内涝”，“大雨”是其调节的上限，需要根据实际情况采用灰绿结合的手段来落实。因特大降雨引发自然灾害，应该考虑的不再是雨水抵御策略，而是灾害应对策略，即如何保障人民生命财产安全，以及将生命损失和经济损失降至最低。[20][21]2021年7月河南郑州地区的“7·20”特大暴雨事件便是如此，持续降雨量已经超出海绵设施系统和城市排水系统能够共同分担的水量上限，需要启动以保护居民安全和减少财产损失为目的的应急预案。海绵城市建设的优势在于其韧性优于灰色基础设施，能够起到延缓灾害发生时间和降低灾害影响的强度作用，灾后恢复速度会更快、经济损失也更小[2][22]。

二是建立海绵城市建设全过程的工程管理体系。海绵城市建设涉及立项评估策划、场地规划、方案设计、方案评估、方案优化、施工图设计、施工、验收、管理、运营维护等多个环节。获益于水模型等的应用普及，评估策划、规划和设计阶段的各个参与方已经意识到并基本做到了海绵城市建设的精细化需求[23][24]。未来最需要转变观念与工作方法的是施工环节。笔者研究团队在实地考察中发现，施工单位观念固化，施工中低精度取值、粗放放线、工序不规范等现象普遍存在，无法适应海绵城市建设的精细化施工需求。

三是必须明确主管部门、设计团队和施工单位的责任。目前，由于部分规章制度体系不完善，因此缺乏对设计方案与落地方案的一致性评估，以及方案调整责任与工作程序等具体要求。主管部门高度重视立项评估策划、场地规划、方案设计等前期环节，而施工等后期环节仍未发生实质性改善；设计团队对场地调研不细致，完成的方案落地性较差；施工单位随意调整方案，或发现显而易见的缺陷仍然坚持“按图施工”，呈现出主管、设计与施工脱节的现状，彼此间的协作并未能更好地完成项目，规避或推卸应该承担的责任时有发生。

举例而言，参照《海绵城市建设技术指南》，设计师设计下沉式绿地时下凹深度往往取值150mm。而在实际施工过程中，预留的150mm蓄水层极易被新栽植被自带的土球填补，削弱甚至抹杀其应当发挥的效果。最常见的错误有以下几点：1）收水口高于路面，径流无法进入雨水花园；2）溢流口正对入水口，径流在进入雨水花园后立刻溢流；3）雨水篦子设在收水口，径流直接进入市政管网（图3）。和过去的城市园林绿化和市政工程不同，海绵城市建设是一项精细化事业，要求评估

and regional scales and re-harmonizes the nature and human society. In the future, there are some difficulties need to be solved.

First, Sponge City construction as a means of urban storm water management is to facilitate on-site runoff retention and address urban waterlogging problems. When storm occurs, the on-site runoff volume exceeds the regulation capacity of sponge facilities, and gray infrastructures must be introduced accordingly. At times when storms cause natural disasters, rather than developing strategies of resistance, it requires to formulate strategies of disaster risk control to minimize the loss of people's lives and property. [20][21] In 7·20 Zhengzhou Storm, a cruel storm in Zhengzhou, China, the continuous rainfall exceeded the combined capacity of the sponge and municipal drainage systems, which demands the implementation of flood emergency response plans. Sponge City construction is of a greater resilience than gray infrastructures in delaying the flood peak and diminishing disaster impact, with a shorter recovering period and less economic loss[2][22].

Secondly, establishing a whole-process management system for China's Sponge City construction projects that involves a series of stages—approval assessment, planning and design, plan assessment and optimization, drawing construction schemes, construction, work acceptance, and post-occupancy management, operation, and maintenance. As the promotion of applications such as water simulation models, professionals from earlier stages of approval assessment, planning and design need to meet the requirements of refined standards[23][24]. There is a pressing call for changes in working mindsets and methods in the construction stage. Through field investigation, the authors found that the existing workflows and construction precision control of most construction teams are inadequate for the standards of Sponge City construction projects.

Thirdly, the identification of accountability and responsibilities of the administration, design, and construction parties. The existing regulation system does not cover more detailed specific requirements such as the consistency between the schemes of design and construction, the responsible party for scheme adjustment, and work flows. The administration agencies strengthen the examination of earlier stages such as approval assessment and planning and design but leave the later stages such as construction unchanged, while the design team's hasty on-site investigation often leads to construction difficulties, and the constructors often arbitrarily adjust the designed scheme or lack flexibility. Such disjunction has also likely led to responsibility evading problems.

For example, according to the Sponge City Construction Technology Guidelines, a piece of sunken green space is usually designed 150-mm in depth for rainwater retention. However, this small elevation design is often overlooked in construction and filled with soil carried by the newly planted vegetation, undermining the actual rainwater retention capacity. Other commonly found mistakes are: 1) water intakes of rainwater gardens are placed higher than the road surface, where road runoff cannot flow into; 2) the overflow outlet is placed too close to the water intake, where the runoff immediately passing through the garden; 3) and the inlet of municipal drainage pipe systems installed aside the water intakes, where the runoff flows into

定量化，设计、施工和管理维护精细化。同时城市居民对环境的要求和审美水平已经大幅提升，这对海绵城市建设质量提出了更高的要求。这一变化对相关参与方的专业知识、合作意愿与职业素养提出了巨大挑战。

四是亟待转变认知和技术观念。海绵城市建设属于城市生态修复范畴，代表城市发展观念和发展方式的转变，其成效需要较长时期才会显现。不能因为一些极端天气气象事件就否定海绵城市建设，乃至否定整个城市的生态修复和生态保育工作。从气候周期来看，北方降雨未来可能会逐年增多，类似此次郑州的特大暴雨事件仍有可能发生，所以有必要进一步强化应急海绵设施建设与气象灾害应急预案系统的结合，才能更加有效地保护人民生命及财产安全。应急海绵设施建设标准应与现行灾害分级响应系统[25]相互吻合，如市政管网建设标准应足以应对能够触发Ⅳ级响应及以下的雨情；30～50年一遇防洪标准对应能够触发Ⅲ级响应的暴雨雨情；50～100年一遇及以上的防洪标准对应能够触发Ⅱ级及Ⅰ级响应的极端天气气象事件[26]。同时，应加强风险评估，如通过数字模拟等手段评估即时雨洪管理系统的排水能力，明确洪水通道，划分各区域内涝风险等级等。若能提前预测雨洪风险，就可实施更具针对性的措施，减轻灾害损失。

5 知识链接与人才培养

水问题的症结看似在水，实则在“岸”。专业技术人员如果不能准确把握“水是如何流的”，将会深刻影响海绵城市建设工作质量。和水

3. 常见海绵设施落地问题：拦截坝最低处已高于旁边道路（图3－1）；道牙开口正对溢流井（图3－2）；雨水花园被种植土侵占了蓄水空间（图3－3）；雨水篦子正对溢流井（图3－4）。

3. Common problems seen in Sponge City construction projects: the lowest point of the interception curb is higher than the adjacent road surface (Fig. 3-1); the overflow well is wrongly positioned too close to the curb opening (Fig. 3-2); the water retention space in the rain garden is filled with plant soil (Fig. 3-3); and the inlet of municipal drainage pipe systems is installed too close to the water intake (Fig. 3-4).

the pipes (Fig. 3). Unlike previous urban gardening and municipal landscaping, Sponge City construction has a set of refined standards that requires quantitative assessment and delicate design, construction, management, and maintenance. Meanwhile, professionals are also facing challenges in expertise, cooperation spirit, and competence, with citizens' higher demand for quality Sponge City construction as their improvement in environmental perception and aesthetic appreciation.

Last but not least, the urgent need to update knowledge and technical perception. Sponge City construction is part of urban ecological restoration that usually takes a long time to take effect, which requires professionals change their understanding and approaches to urban development and construction. People should not deny the benefits of Sponge City construction, or even the efforts in urban ecological restoration and conservation, by once extreme weather event. According to the predicted annual rainfall increase in North of China, the frequency of disasters such as 7·20 Zhengzhou Storm would very likely intensify, which necessitates the enhancement in combining sponge facilities construction for emergency with meteorological disaster emergency strategies so as to more effectively protect the security of people's lives and property. The construction standards of such sponge facilities should be consistent with the China's disaster classification and response strategies[25]. For instance, the construction standards of municipal drainage systems should be able to withstand rainfalls of Level IV; the standards for 30- to 50-year floods should be able to withstand rainfalls of Level III; the standards for 50- to 100-year and severer floods should be able to withstand extreme weather events of Level II and I[26]. Meanwhile, it is essential to emphasize risk assessment via digital simulation such as evaluating the immediate drainage capacity of storm water management systems, identifying flood paths, and grating flood risk levels of different areas. More targeted measures can be carried out to mitigate the loss if the storm water risk can be more accurately predicted.

5 Expertise Collaboration and Talent Training

Water problems are often causal to land problems. If professionals do not grasp basic mechanisms about rainwater such as how the water flows, they could


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生态修复等其他水环境治理工作一样，海绵城市建设各环节都涉及诸多专业。无论是为了应对排水防涝所进行的宏观灰绿基础设施系统建设，还是为了源头减排所进行的微观雨水设施建设，都需要综合考虑竖向设计、排水路径、生态修复、审美和居民使用等。完成这一任务，需要城市水文学、气象学与大气科学、综合自然地理学、生态学、给排水科学与工程、市政工程、城市规划和景观设计等多领域和多学科的专业知识。只有做到各环节紧密衔接，实现真正的跨专业合作，各专业技术人员各司其职、协同作战，才能使各项治理措施有效发挥作用。[27][28]

海绵城市建设存在突出的“人才短缺”问题：一是能够深入某个领域的“专门人才”短缺。当下的海绵城市建设，不论是设计、施工，还是运营维护，每个环节的岗位都缺乏合格的专业人才。在纸上谈兵的高校人才培养方式所营造的浮躁的学术氛围中，迫切需要通过高校的专业教育培养具有实操动手能力、能深入专研某一专业领域并将其做好的“专门人才”，使他们可以直接投入到海绵城市建设实践中，高效完成某领域的具体工作，并且因地制宜地提出水问题解决方案[29]。

二是能够进行深入的专业沟通，实现各个专业环节、流程和领域的知识与技术链接的通识型人才短缺。[30]~[33]在未来的海绵城市建设相关的各项实践中，亟待解决的问题也会越发复杂，对于环境品质的要求会越来越高，跨领域、跨专业团队协作将越来越普遍。因此，专业教育中亟需加强跨学科交流与合作，培养综合性人才。他们应当具有多专业的基础知识储备，善于沟通；在实践中亦能统筹思考、明确功能性目标，协调各环节及不同专业领域技术人员的合作。[34]~[36]这样的综合性人才方能胜任制定总体方案的景观设计师，以及当前各类建设项目中所要求设置的总工程师等角色，从而更好地服务人居环境建设。

在海绵城市建设开展期间，笔者发现，很多景观设计公司 / 团队引进了较多市政工程、城市水文学、生态学专业的专业人员。[37]另外，近年来涌现出一批整合了景观设计与给排水科学与工程专业的新兴企业，专攻海绵城市建设。这的确是一个良性变化，但就行业现状与发展趋势来说，这种仅存在于团队内部的跨专业协同合作还远远不够。[38]

此外，能够统筹海绵城市建设工作的专业人才缺乏，从业者对景观设计统领海绵城市建设工程落地的认识普遍不足。[39]海绵城市建设需要从区域到场地尺度上整合水文过程与形态，涉及了人的需求与生活质量提升、物质空间、生物环境、技术、材料等方方面面，涵盖评估策划、

not develop design schemes of quality Sponge City construction projects. Like other water environmental management measures (e.g. water ecological restoration), different stages of Sponge City construction involve various specialties. Sponge City constructions across scales—from city-scale grey-green infrastructures for drainage and waterlogging control to site-scale storm water facilities for source control—all need to integrate vertical design, drainage path design, ecological restoration, aesthetics quality, residents' demands, etc. This entails the multidisciplinary collaboration among experts in Urban Hydrology, Meteorological and Atmospheric Sciences, Integrated Physical Geography, Ecology, Water Supply and Drainage Science and Engineering, Municipal Engineering, Urban Planning, and Landscape Architecture. Only when such inter-professional cooperation is truly realized, can the projects have expected ecological and social performance.[27][28]

China's Sponge City construction is challenged by a serious talent shortage. Firstly, there is a huge talent gap in design, construction, operation, and maintenance of current Sponge City construction. At present, upon the curriculum of Chinese colleges and universities, graduates are mostly trained through the desk study, with less opportunities to exercise. Students should be to trained into talents with exercise who can readily contribute to Sponge City construction and efficiently complete specific works by devising appropriate solutions to water problems according to site conditions[29].

At the same time, it also sees a shortage of generalists who can carry out in-depth inter-professional and technical coordination in each stage and process of Sponge City construction.[30]~[33] In the future, Sponge City construction practice would come up with higher environmental requirements and encounter with more complicated problems, which would lead to more inter-professional team collaboration. Therefore, it urges the strengthening of generalists' cultivation in college education. Graduates should have multi-disciplinary basic knowledge and outstanding coordination skills, use to integrated thinking, and be capable of identifying the hierarchy of objectives in each project stage.[34]~[36] Such generalists are expected to be competent for roles such as the landscape architect who formulates the master plan, and the chief engineer as that in other construction projects.

In the practice of Sponge City construction, many landscape architecture companies/teams have increasingly recruited professionals from Municipal Engineering, Urban Hydrology, and Ecology.[37] Gratifyingly, in recent years there are many newly founded enterprises that specialize in Sponge City construction, and team members include landscape architects, water supply and drainage engineers, etc. However, such individual inter-professional teams are not enough to promote the transformation and development of the entire profession.[38]

Lastly, the scarcity in competent candidates for the leading role in Sponge City construction. The fact that landscape architects is not broadly recognized enough as the suitable role.[39] As discussed above, Sponge City construction requires integrating water processes and forms across scales, with considerations

场地规划、景观设计、监测、施工、融资、评价等不同业务。[40]~[42]海绵城市建设本质上是“结构体系设计”（Architecture）。海绵城市建设必须能够找到解决或者纾缓城市人居环境面临的水资源短缺、水环境污染、水生态系统退化、洪水内涝、城市开放空间难以满足人们生活需求等实际问题的方案，同时为人们提供更加宜人的城市生活环境，这一工作才可能为人们所接受。海绵城市建设工程的实施即为景观建设（Landscaping）。海绵城市建设这样的工作要求决定了其工作性质一定是整合性的，是对特定土地区域的全要素、全过程和全生命周期的理解、评估和重构，综合制定问题的解决方案，最可能完成好这一任务的是景观设计。景观设计学（Landscape Architecture，即目前一级学科所使用的名称“风景园林学”）本质上是土地设计、物质空间规划，是建立在探讨针对土地上存在的环境、生态、社会问题解决方案的自然科学、工程技术与人文社会艺术科学相结合的应用学科。景观设计学的这一特征，为海绵城市建设如何落地指明了方向，使景观设计学具备担当统领海绵城市落地的任务的天然优势。[29][43]

6 海绵城市建设常态化机遇与国家政策

在中国“双碳”战略机遇期，应当意识到海绵城市建设缓解城市热岛效应、促进建筑能耗降低等的作用。海绵城市建设有助于二氧化碳减排，与“双碳”目标具有一致性。[44]因此，有望借力“双碳”机遇，将雨水收费制度融入碳汇交易市场，利用金融体系来支撑海绵城市建设。与此同时，相关规范立法也有待完善：如若借鉴西方国家经验，将雨水作为面源污染源，就为立法收费提供了合理性。[45]~[49]目前国际上以不透水地表的面积为重要定额参数，向土地权属人征收污染处理费用的收费方式比较常见[50]。考虑到不同国情，中国的雨水收费机制还需进行本土化探索。通过立法收费为海绵城市建设和维护提供资金保障是大势所趋，必须在未来工作中稳步试点和推进。[51]~[53]

海绵城市建设的常态化需要在国家政策的支持下寻求体制上的突破。其作为城市的基础工作，需要大量资金投入以开发出一套可持续的发展方式，因而有必要优先解决资金来源问题[54]。目前，海绵城市建设资金主要源于国家财政的支持，这显然是不可持续的。应当使政府投资（如出资购买相关服务）发挥带动作用，鼓励探索新的市场机制模式。

海绵城市建设的常态化同样有赖于国家相关政府部门对创新型产业发展的支持。当前建设施工问题频发，主要原因之一在于缺乏标准化产品和技术，施工过程依赖人工技术，一旦出现施工人才短缺状况，极易

of human needs and life quality improvement, physical space creation, biological environment optimization, as well as related technologies and materials, covering approval assessment, site planning, landscape design, monitoring, construction, financing, and evaluation.[40]~[42] The essence of Sponge City construction is “structural system design” (i.e. Architecture), and will be commonly recognized when it shows the potential in resolving or relieving actual problems (e.g., water shortage, water pollution, aquatic ecosystem degradation, flood and waterlogging, and unsatisfactory urban open spaces), while creating a more pleasant urban living environment. The integrated nature of this work is defined by its requirements that is to understand, evaluate, and reconstruct all sorts of elements, whole process, and full life cycle of a given site, and to make comprehensive solutions. Thus, intrinsically, the implementation of Sponge City construction is a process of “landscaping.” In essence, Landscape Architecture is a discipline about land design and physical environmental planning, and an applied science that combines natural science, engineering technology, and humanities and social arts, exploring solutions to environmental, ecological, and social issues on the land. This discipline and profession mission of Landscape Architecture enables it to take leadership in directing Sponge City construction.[29][43]

6 Institutionalization and National Policy for Sponge City Construction

In the context of China’s Dual Carbon policy, the importance of Sponge City construction to Dual Carbon goals—alleviating the urban heat island effect and reducing building energy consumption—should be emphasized.[44] It is possible to introduce storm water billing system into the carbon trading market as a part of funds for Sponge City construction projects. For example, identifying storm water as non-point source pollution, as Western countries do, might be adopted in relevant legislation.[45]~[49] At present, it is internationally common to charge landowners for pollution treatment fees mainly by the area of impermeable surface[50]. Aside from drawing experiences from other nations, China’s storm water billing system also needs to be altered according to the national situation. Generally, in the future it needs to legislate to guarantee the financial sustainability of Sponge City construction and maintenance.[51]~[53]

China’s Sponge City construction needs to seek institutional breakthrough with the support of national policies. Primarily, Sponge City construction, as a kind of urban infrastructure, is funded by national appropriation and challenged by a huge funding gap, which matters its development and sustainability[54]. Government investment such as paying for related design and construction services should be dominant in the future, and the exploration of new market mechanism models is also encouraged.

The institutionalization of China’s Sponge City construction can also be promoted as along the development of innovative industries. One of the main reasons for frequent construction problems is the heavy dependence on manual

影响整体工程施工质量。在国家政策支持下，通过技术创新建立海绵城市建设产品体系，直接采用标准化产品，将会大大提升海绵城市建设效率与效果[55]~[57]。

在政策导向方面，引入更合理的激励机制能够持续性地促进和引导技术体系向下推行。以风险评估为例，作为针对性规划的重要步骤，规划设计师完全可以胜任此项工作。而在现有政策条件下，制作评估模型既耗费精力又无法获得相应的经济收益，显然很难激发技术人才主动投入到此类必要的前期研究工作中。[58]~[60]

最后，为进一步助力现有政策机制的有效推进，可以尝试将已经具有一定理论研究基础的理念应用于实践。[34][61]~[64]例如，借鉴最大日负荷总量（TMDL）控制计划的污染负荷分配方式，将考核污染物的实际控制量是否达到被分配的控制额度纳入海绵城市建设的顶层设计，使径流控制率与受纳水体的水质指标直接挂钩，优化径流控制率的规划和设计，避免目前有些地方为了“海绵”而“海绵”的面子工程。TMDL可以成为河长制的抓手并纳入评判河长的工作成效的评价体系——有助于改进现状海绵城市建设的监测评估方法，亦有助于推动更多中国城市将海绵城市建设纳入综合性城市水系统管理方案。[65] LAF

work and the lack of standardized products and technologies. In practice, the absence of skilled constructors would greatly affect the overall construction quality. Under national policy support, the construction efficiency and project performance can be improved significantly through the promotion of standardized sponge products[55]~[57].

In terms of policy orientation, new incentives should be introduced to ensure the sustainability, promotion, and guidance of related technological system. For instance, while planners are perfectly qualified for but unwilling to conduct risk assessment—a necessary process in targeted planning via modeling methods. Under the existing policies, such preliminary studies are time-consuming but poorly rewarded, which harm researchers' motivation or initiative.[58]~[60]

Finally, applying theoretically verified ideas into practice would also help promote the current policy mechanism.[34][61]~[64] For example, drawing on the idea of Total Maximum Daily Loads (TMDL) for pollution load distribution, the actual pollution load to its designed one can be employed as part of the evaluation criteria on the water quality of Sponge City construction projects. This would facilitate the optimization of runoff control plan. The indicator could to be adopted into the River Chief System as a performance monitoring criterion of Sponge City construction, to push forward the incorporation of Sponge City construction into the integrated urban water system management plans in more Chinese cities.[65] LAF

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