

城市河流社会 - 经济 - 自然复合生态系统构建 ——长沙市圭塘河流域治理与生态修复 规划设计

A SOCIAL-ECONOMIC-NATURAL COMPOUND ECOSYSTEM CONSTRUCTED FOR URBAN RIVERS — PLANNING AND DESIGN FOR THE REMEDIATION AND ECOLOGICAL RESTORATION OF THE GUITANG RIVER WATERSHED IN CHANGSHA CITY, CHINA

1 引言

城市河流是由社会、经济和自然系统耦合而成的复合生态系统，涵盖人类活动、城市生活、文化和历史等社会生态因素，河道、湿地和绿色廊道等具有特定生态功能的自然生态因素，以及流域和岸线范围内城市经济建设发展的制约和需求关系等经济生态因素^[1]。

河流是早期城市建设选址的重要因素，彼时的河流生态系统几乎不受人類活动的影响。但自进入工业文明时代以来，城市的迅速扩张逐步蚕食了滨河空间，也使河道逐渐渠化。与此同时，由于大量自然蓄水空间被填埋，人们不得不建造更高的防洪堤坝，从物理空间上严重割裂了城市与河流之间的联系，自然水平衡亦遭破坏，加之愈发严重的水体污染，城市发展与河流生态保护之间矛盾重重。

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摘要

圭塘河作为湖南省长沙市最长的城市内河，曾是一条人水和谐的自然河流，如今随着城市迅速扩张，其水资源、水环境和水生态问题日益严峻，甚至成为了城市发展的障碍。受长沙市圭塘河流域开发建设有限公司委托，项目团队以重塑圭塘河自然水循环过程为设计目标，综合运用水系水动力模型、水质模型、排水管网水动力模型和流域水文模型辅助寻找最适宜的规划方案，借此提出融合蓝绿生态网络与城市功能分区、恢复自然河道、优化河岸空间、构建流域尺度生态廊道和实施街区尺度海绵城市建设等策略，完成了由面（整个流域范围）及线（圭塘河），再由线到点（街区尺度的具体项目）的跨尺度流域治理规划。该规划旨在让河流回归自然，构建融社会、经济和自然于一体的城市河流复合生态系统，化解城市发展与生态系统构建之间的重重矛盾，实现城市河流的可持续发展。

关键词

社会 - 经济 - 自然复合生态系统；流域治理；数学模型；城市发展；跨专业协作

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ABSTRACT

Guitang River, a once natural river breeding a harmonious human-water relationship, is now the longest inland river of Changsha City, Hunan Province, China, suffering from severer water problems such as water shortage, environmental pollution, and ecological degradation, which heavily impede the urban development. Commissioned by Changsha Guitang River Catchment Development and Construction Co., Ltd., the project team employed 4 mathematic models including a hydrodynamic model of water systems, a water quality model, a hydrodynamic model of drainage networks, and a hydrological model of watersheds to generate an optimal planning scheme for restoring the natural water circulation with the most appropriate planning scheme. Strategies were proposed including the blue and green ecological network combined with urban functional zoning, natural river restoration, riparian space improvement, watershed-scale ecological corridor construction, and neighborhood-scale sponge city construction. The whole planning and design, from a coordinated planning at the watershed scale to the river scale, and to specific neighborhood projects, is to establish a social-economic-natural compound ecosystem to balance urban development with ecosystem improvement, while promoting the sustainability of the river.

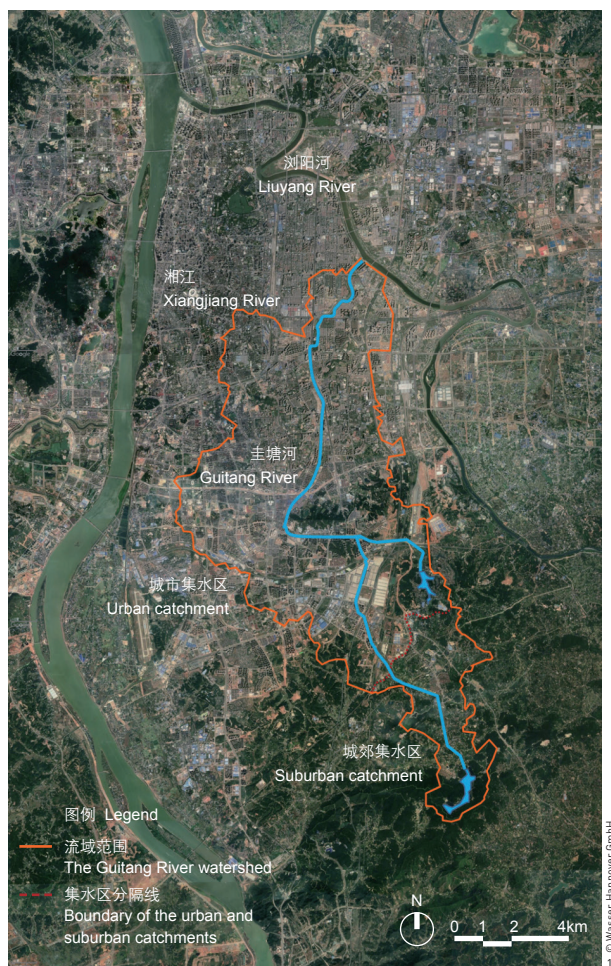
KEYWORDS

Social-Economic-Natural Compound Ecosystem; Watershed Remediation; Mathematic Models; Urban Development; Multi-Disciplinary Collaboration

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1. 圭塘河流域大部分为城市区域，仅上游小部分区域为乡村。
1. The Guitang River watershed covers a large territory of urban area while consisting of a small rural area in the upper reach.



对设计师而言，单一专业视角或仅关注河岸线性空间的建设并不能从根源上化解这些矛盾，更需要在城市发展的过程中，尽可能实现河流自然系统与社会、经济系统的融合。因此，聚焦河流复合生态系统的构建，让河流回归自然功能，兼顾社会生态系统和经济生态系统的需求，才是未来城市河流及其流域的治理方向。在治理过程中，设计师作为搭建各个生态组件的主导者，需要具备系统思维模式，并借助数学模型等工具，分析问题症结，综合考虑各方利益需求，尽可能达到各个组件之间的和谐共存和可持续发展，化解城市发展与生态系统构建的矛盾。

2 项目背景和问题

圭塘河位于长沙市东南部，是长沙市中心区最长的城市内河，起于跳马镇石燕湖水库，向北汇入浏阳河，为典型的季节性山区河流。据2017年最新测量数据，目前河道长25.3km，集水区面积达108.6km²（图1）。

20世纪中叶，圭塘河曾是一条蜿蜒曲折、水质清澈的自然河流，河道长37.3km，两岸有大量用于鱼类养殖和灌溉蓄水的自然池塘，河道与池塘水面总面积达868hm²。到20世纪90年代，河道中游被裁弯取直，支流基本消失，河道空间被严重压缩。现今，圭塘河84%的集水区已被用于城市开发，上游城郊农田结构发生明显变化，其他区域的土地利用更是经历了剧烈变化，河流水文特征随之显著改变（图2）。

就水资源而言，河道上游目前仅存两个集水区总面积约4km²的小型水库，周边旅游项目的开发增加了其为下游补水的难度，渠化河岸切断了流域内地表水与地下水的自然交换，导致河道生态基流难以保障，非降雨期基流主要为污水处理厂尾水。高硬化率和雨水调蓄空间的丧失也使得城市内涝频发，不断升高的历史最高洪水位加剧了城市的水安全隐患。在水污染方面，圭塘河流域当前多数为合流制排水系统，雨污管网混接现象普遍，被污染的雨水、污水处理厂尾水、农业面源污染等直接造成水体黑臭，两岸的屠宰场和露天贸易市场等更加剧了这一问题。在水生态方面，平直而硬质的河道完全丧失了原本的自然结构，严重影响了生态多样性；拦水坝等设施也阻断了河道的生态连续性。此外，紧邻河岸的快速车道成为城市与河流之间的一道鸿沟，进一步限制了市民的亲水活动。在某种程度上，圭塘河已成为城市发展的障碍（图3）。

3 基于流域尺度的圭塘河治理规划

3.1 设计目标

通过基于自然的解决方案，设计团队期望重塑圭塘河的自然水循环过程，建立长沙市水生态体系的可持续运行机制。具体措施为：恢复自然河道形态，在实现防洪防涝的同时，保障河道生态基流；结合海绵城市建设和河道改造，优化土地利用和土地覆盖类型；整合生态净化设施，提高污水处理厂排放标准，从而提升河道水质，最终修复流域生态体系。

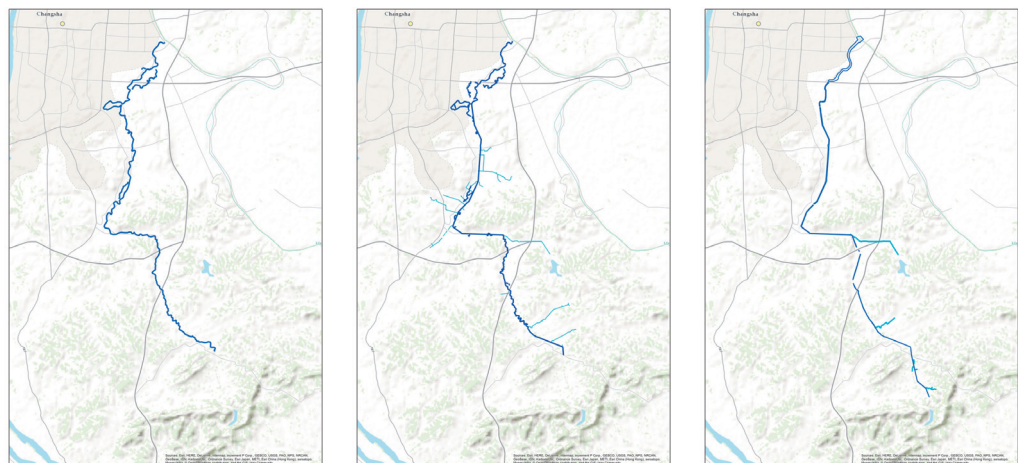
圭塘河流域的规划与设计需协同城市规划与设计、景观设计、生态修复和水利工程等多个专业，首先通过流域尺度的统筹和规划，将河道生态系统修复与长沙市的发展相结合，进而完成由面（整个流域范围）到线（圭塘河）的跨尺度设计，形成圭塘河流域的治理规划；再由线到点（井塘海绵城市示范公园等具体项目），通过沿河开发带动产业转型与升级。由此从多个维度提升河道的整体环境和生态潜力，构建社会—经济—自然复合生态系统（图4）。

3.2 设计过程——数学模型辅助规划设计

项目涉及河流水系、城市排水系统及海绵城市体系等多个系统，且需要跨专业协调，相关因素多且复杂，因而设计团队借助数学模型进行研究，探索平衡社会经济发展与流域水环境治理需求的规划设计方案。设计过程中共建立了水系水动力模型、水质模型、排水管网水动力模型，及流域水文模型4个数学模型（图5）。

水系水动力模型可对主河道的枯水流槽形状和坡度、浅水区和湿地的面积，以及生态护坡的材料等生态组件的性质及其在不同洪水情景下的状态进行模拟，为河道防洪和生态修复设计提供重要参考依据。在本项目中，首先根据河道现状资料建立圭塘河现状水系模型，并利用实际降雨数据和河道测量数据对模型进行率定和验证，直至洪水事件模型模拟结果与实际测量结果高度吻合。而后使用该模型模拟现状下的百年一遇洪水，并据此对防洪堤进行调整或重新设计：在上游农田区域，借助现有地形设置调蓄空间；在中下游城市区域，根据河道周边用地类型和地形情况，拆除现有硬质岸线，扩大河道断面，针对枯水期、中水期和洪水期水位创建多样化的生态化河流断面结构。之后使用该模型分别模拟上述改造实施后，河道在两年一遇、10年一遇、20年一遇、50年一遇和百年一遇情景下的洪水水位、流速，以及对河岸与河床的冲刷程度。不同的水位模拟结果可为河岸景观设计和防洪设计提供依据，同时协助明确河道沿线雨水排口在不同降雨情景下所受的影响。不同流速的洪水对河岸及河床的冲刷程度模拟结果则可用于指导河道生态化护岸措施及材料的选择，有助于优化建设投入，以尽量低的成本实现最佳抗冲刷效果（图6）。

水质模型、排水管网水动力模型及流域水文模型之间联系较为紧密，经过率定和验证后，可用于整个流域的现状建模与治理前景模拟。本项目首先使用水质模型计算圭塘河的污染负荷，通过流域水文模型确定河道目前最主要的污染来源为城市排水系统，并通过排水管网水动力模型模拟识别出易发生内涝的区域，再依据上述结果，优化城市排水管网，规划雨污分流系统（图7）；结合地形分析，规划蓝绿生态廊道，明确超标雨水排放通道；在临近河道的排口设置雨水沉淀池/溢流池和生态滤池系统，减少入河污染物的排放。之后，使用流域水文模型对以上措施的实施效果进行模拟，发现仅依靠末端截污、对雨污合流溢流水进行生态处理等手段，虽然可以显著提高河道水质，但仍然难以完全达到水质等级目标，因此提出进一步实施源头控制，



在城市内进行街区尺度的海绵城市建设。最后，再次用水质模型模拟实施上述措施后的流域水质状况，以判断措施的有效性和可行性。通过反复论证调整设计和模型，设计团队对不同解决方案的投资和成效进行了量化比选，最终确定了最适合圭塘河流域的规划方案。

3.3 规划设计方案

3.3.1 融合蓝绿生态网络与城市功能分区

在空间上，将圭塘河流域周边贯通南部多个城市的森林涵养地（长株潭城市群生态绿心地区）、城市山体林地（湖南省森林植物园等）及带状的浏阳河生态廊道等绿地斑块整合为蓝绿生态网络（图8）。再结合不同河段的水文特征、河道功能及其相邻城市区域的需求和边界条件（图9），制定不同的治理对策、生态修复目标与城市发展战略（图10，11）。例如，在上游农业区域构建洪水调蓄空间、连通池塘网络、开发旅游目的地等；在中游进行污染调控、融合城市功能；在下游主要实施沉积物管理和防洪工程等。

蓝绿生态网络构建与城市开发改造的紧密融合将极大改善圭塘河的生态环境，促使沿河城市面貌发生积极改变，丰富居民的休闲生活空间。环境质量的提升也将带动城市品质的提升与周边土地的升值，促进圭塘河沿线低附加值产业向高附加值产业转型。

3.3.2 恢复自然河道

通过暴雨查算手册和模型模拟计算验证，圭塘河河口处百年一遇洪水的峰值径流量约 $604\text{m}^3/\text{s}$ ，两年一遇洪水的峰值径流量约 $118\text{m}^3/\text{s}$ ，枯水期测量流量约为 $1.1\text{m}^3/\text{s}$ ，差别巨大。根据水系水动力模型对非降雨基流、降雨排水、暴雨泄洪等不同情景下河流水位、流速以及河岸冲刷程度的模拟结果，方案相应设置了枯水流槽、自然河道和行洪通道

- 20世纪70年代：圭塘河河道蜿蜒曲折（左）；20世纪90年代：圭塘河中游部分河道已经渠化（中）；现如今，圭塘河主河道几乎完全平直化，河道长度缩短（右）。
- 亟待修复的圭塘河
- The winding Guitang River in the 1970s (left); the river with canalized middle reach in the 1990s (middle), and the present river with straight and shortened main channel (right).
- The existing Guitang River urgently requires a restoration.

等水流路径，并配置了适宜的护岸材料和水生植物。其中枯水流槽宽度小于原自然河道宽度，可在枯水期增加河流水深，形成蜿蜒的水道和深潭浅滩，既可为动植物提供多样化的栖息地，也有助于提升水体的自净能力；河道两侧的部分公园及绿地在洪水期可作为临时淹没区域，以扩大洪水过流断面，增加河流蓄洪空间（图12）。

3.3.3 优化河岸空间

圭塘河中下游有限的河岸空间不仅需承担生态功能，还应满足众多的社会需求。高程低于防洪水位标高的区域需同时满足慢行系统建设、休闲娱乐、生态水处理和行洪等功能。可将水动力模型模拟结果作为设计依据，根据不同的过洪断面及景观功能需求，灵活地对河岸空间进行平面和竖向布局。例如，将使用频率较高的广场、市政道路等设置在百年一遇洪水水位之上；儿童游乐场可设置在百年一遇和50年一遇洪水水位之间；可作为临时行洪或调蓄空间的景观水体或运动场地可设置在20年一遇和50年一遇洪水水位之间；滨水步道可稍高于5年或两年一遇洪水水位，以满足被频繁淹没的需求（图13）。此外，设置在雨水排口附近的水处理设施也需与河岸空间相结合。设计中采用沉淀池和生态滤池来控制合流制排水系统的污染物，就地净化后的水体可补给河水。

在上游农田区域，可通过用地性质的改变来改善水文状况。例如，在现状河谷地带设置临时蓄洪区，种植耐水淹的农作物，同时激

活上游山地池塘的调蓄空间，减缓汇流速度（图14）。

3.3.4 构建流域尺度生态廊道

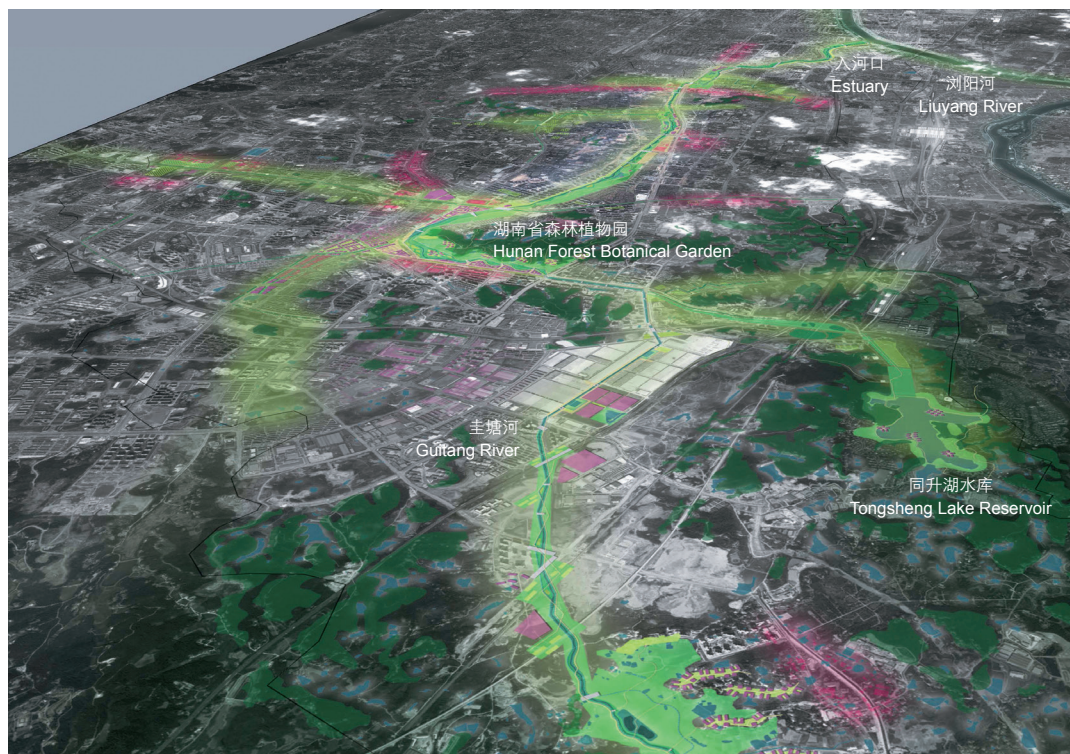
要将圭塘河完全恢复至开发前的状态几乎不可实现，因此需构建流域尺度的生态廊道，以尽可能恢复城市自然水循环过程。构建生态廊道首先需要研究河流历史水文路径、地形标高、现状绿地、城市用地规划及城市更新需求等。除利用现有绿地外，还需要借助城市更新契机，跳出单个地块中水系的构建，充分发挥蓝绿生态网络的作用。

生态廊道可以作为连接城市绿色节点、城市建成区和圭塘河主河道的重要路径，以及超标雨水的排放通道。其在加强单个生物栖息地之间联系的同时，还可连接城市开放空间和滨河空间，将人们从城市引向河边（图15）。此外，生态廊道还可收集周边经过海绵城市措施调蓄净化后释放的清洁雨水，一部分下渗补给地下水，一部分为圭塘河补充生态基流。在发生强降雨时，周边城市区域形成的地表径流可通过生态廊道排入圭塘河，缓解城市内涝（图16）。因此，在进行生态廊道的景观设计时，要充分考虑其季节性、阶段性有水的特征。

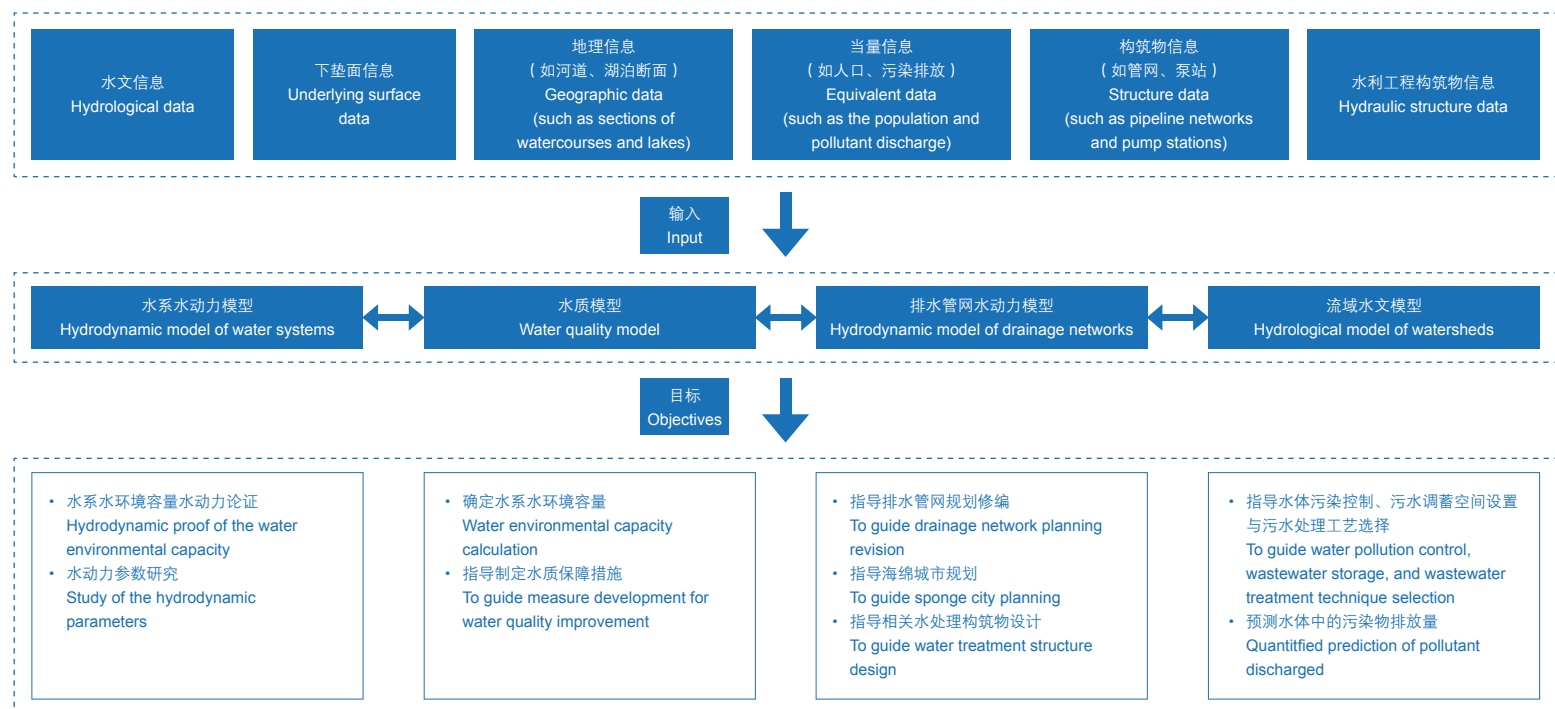
3.3.5 实施街区尺度海绵城市建设

街区尺度的分散式或半分散式海绵城市建设措施可视为流域尺度生态廊道中的“毛细血管”。由于每个城市街区地表硬化率不同，海

4. 圭塘河流域治理与生态修复实践将为城市带来新的形象
4. The watershed remediation and ecological restoration of the Guitang River will reactivate the city.



数学模型的耦合与建立目标
Coupling of mathematical models and the objectives



海绵城市建设措施的介入程度也各不相同，需要将街区尺度的海绵体系建设、城市尺度的排水系统、流域尺度的生态廊道及河道本身作为整体进行统筹考虑，借助流域水文模型，为每个街区制定切实可行的具体建设目标（图17）。

在具体规划中，城市新建区域以不改变自然水文特征为原则，尽量保留现有池塘水体，通过海绵城市建设措施，实现对30mm降水量的调蓄和 $10L/(s \cdot hm^2)$ 的出水量控制，并使不少于50%的硬化区域径流得到净化处理。考虑到在城市建成区实施海绵城市建设措施的经济成本较高，若街区内不具备可利用的调蓄水体，也可适度降低调蓄要求。

4 总结

长期以来，许多城市的流域综合整治存在技术标准不清、跨专业沟通不足、建设管理水平较低、对河流生态功能和需求重视不足、大搞“政绩工程”“形象工程”等问题，使流域治理成为了“开倒车”“摊大饼”和“面子工程”，治理方案也时常出现频繁更换思路等现象。大量重复的工程建设不仅加剧了地方财政负担、造成土地资源浪费，也威胁到政府信用的建设。

由圭塘河流域治理与生态修复规划设计实践可以看出，自然生态系统的构建及其与城市社会经济生态系统的结合是一个复杂且高度

整合的过程，不仅需要不同专业的参与，更需要对不同的目标、利益群体进行通盘考虑，并运用科学方法分析不同生态组件的相互关系，以找出可持续的解决方案。目前，河流沿岸已完成大部分截污工程和部分区间的河岸公园建设，并启动了井塘段海绵城市建设示范公园建设等项目（图18）。圭塘河流域总体规划也将被纳入区域控制性详细规划、蓝线规划、排水防涝综合规划及海绵城市建设指标入库研究，直接作为下一步流域尺度的城市开发和河道两岸开发必须遵守的原则。基于该总体规划可确立系统的技术路线、近中期方案和保障措施等，以确保每一条河流的开发、改造、治理和维护都有章可循、有规可依。**LAF**

项目信息

项目地址： 中国湖南省长沙市
项目面积： 108.6km²（流域面积）
项目委托： 长沙市圭塘河流域开发建设有限公司
项目设计： 德国汉诺威水有限公司
首席设计师： 彭赤焰、Oliver Seidel、Ralf Diekmann、Jens Meisel、Joachim Bengsch
项目负责人： 彭赤焰、Ralf Diekmann
项目团队： 刘苑、王润、郑能师、Oliver Seidel、Tim Mohr、Holger Pabsch、Joachim Bengsch、Lutz Evers、Christian Bouillon、周美月、唐淑甜、Andreas Tangen、李洪浩、Richard Rohlfing、Lennart Wedekind、Uwe Klaus、朱利民、张志能、伍凯、陈少伟、Axel Hermening、许迟君
设计时间： 2017–2019年

5. 通过数学模型分析现状并指导设计
 6. 模型模拟结果可指导河道生态护岸措施及材料选择
 7. 基于水力模型的排水管网优化方案
5. Mathematical models are employed to support status quo analysis and used as design guidance
 6. The simulation results could inform the selection of measures and materials for eco-revetment construction
 7. Drainage network optimization proposal based on the simulation by the hydrodynamic model

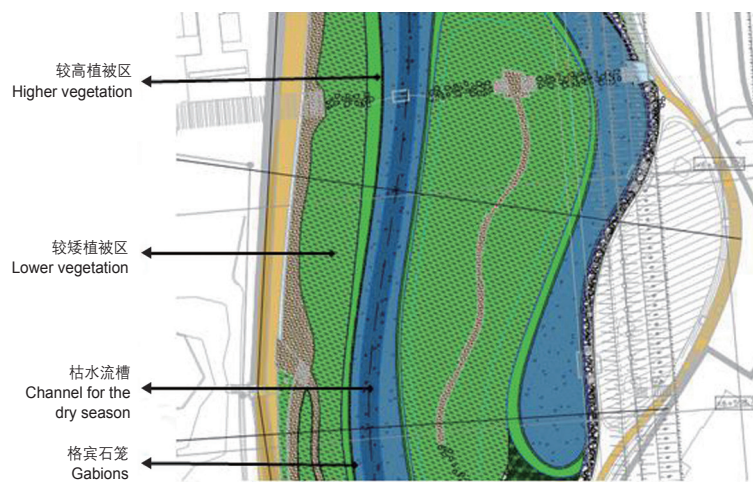
不同种类植被及材料占比
Proportion of vegetation
and materials applied

30% 菖蒲
Acorus calamus
30% 鸞尾科植物
Iridaceae
20% 砾石 Gravels
10% 珍珠菜
Lysimachia clethroides
10% 苔草属植物/金丝雀藨草
Carex spp. / *Phalaris canariensis*

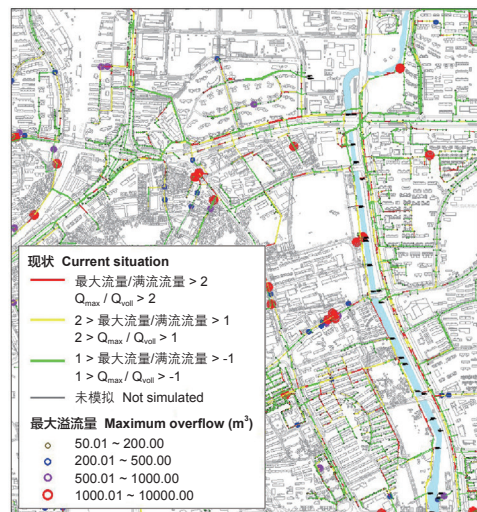
固岸措施

Bank protection measures

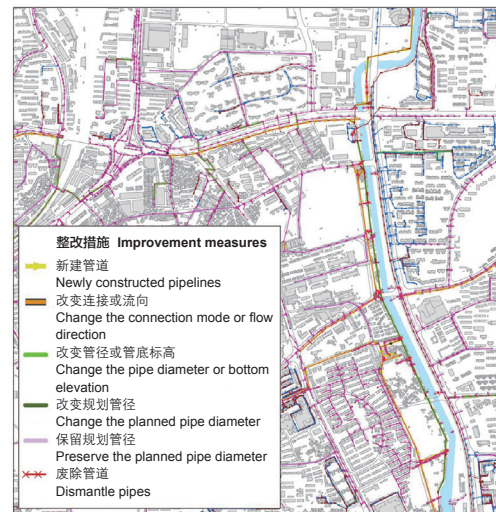
草皮/草皮卷
Turf / Turf rolls
播种植土工布
Seeding geotextiles



现状壅水溢出和超负荷管道 (局部)
Current backwater overflow and overload pipelines
(part of the whole plan)



无壅水溢出的管网规划及整修措施 (局部)
Pipe network planning and improvement measures to
prevent backwater overflow (part of the whole plan)



1 Introduction

Urban rivers are compound ecosystems formed by social, economic, and natural systems, covering the social factors such as human activity, urban life, culture, and history; natural factors such as rivers, wetlands, and green corridors with specific ecological services; and economic factors such as the constraints and requirements of urban economic development within watersheds or along shorelines^[1].

In the early days of human history, rivers were a significant consideration of city siting, when river ecosystems were rarely disturbed by human activity. However, since the Industrial Revolution era, rapid urban expansion has gradually encroached on riparian spaces and resulted in more and more rivers canalized. It has dramatically reduced the number of natural rivers, requiring higher embankments to prevent floods, which make cities severely disconnected from rivers and break the natural water circulation. Water pollution is also getting increasingly serious. The conflicts between urban development and ecological protection of rivers keep intensifying.

At present, these issues can no longer be resolved simply by any single discipline or linear development within riverbanks. Designers should turn to exploring how to build a compound river ecosystem that can restore the natural functions of rivers and promote social and economic development at the same time. In river treatment and watershed management, therefore, it requires designers to think systematically, analyze problems by tools such as mathematical models, and comprehensively consider and coordinate the needs of different stakeholders, to create a harmony among all ecological components of the watershed and explore their potential for sustainable development, while balancing the ecosystem construction and urban development.

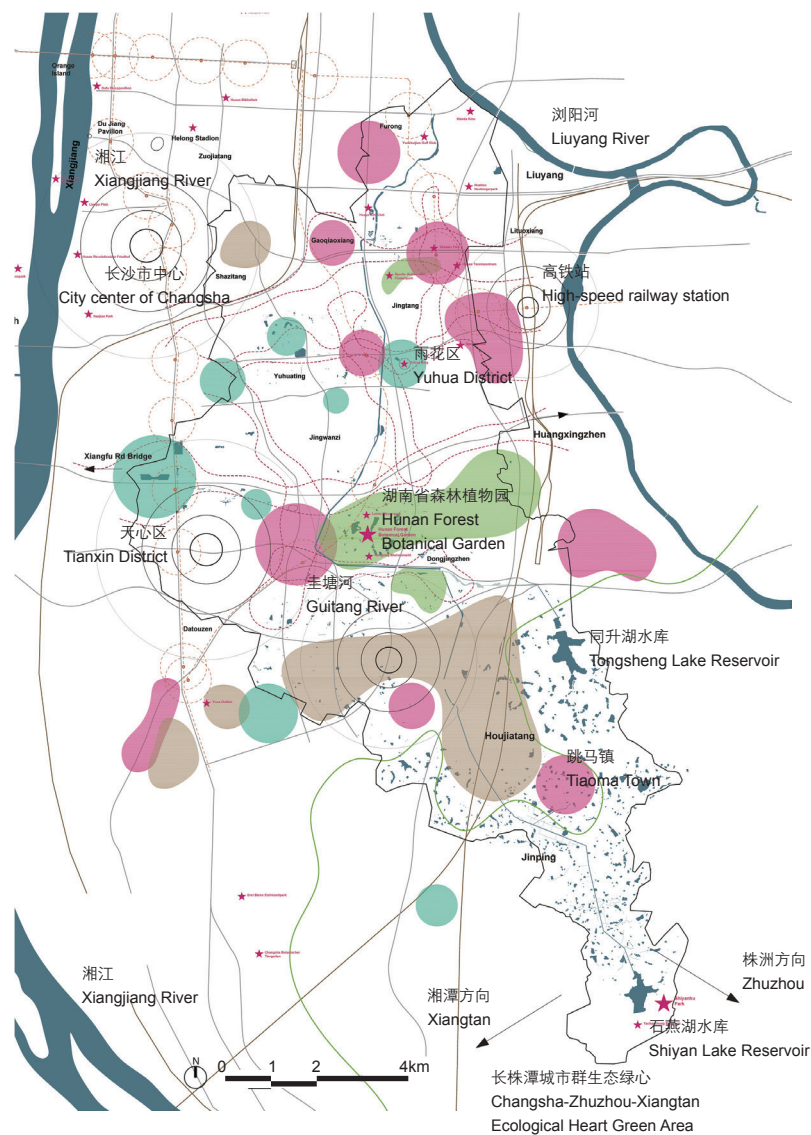
2 Project Background and Problems

Located at the southeast of Changsha City, Hunan Province, the Guitang River is the longest inland river of the city. It is a typical seasonal mountain river draining from the Shiyang Lake Reservoir in Tiaoma Town and running northward into the Liuyang River. According to the latest observation in 2017, the river course is 25.3 km in length, with a catchment area of 108.6 km² (Fig. 1).

In the mid-20th century, the Guitang River was a meandering and crystal-clear natural river in a length of 37.3 kilometers. Along it there were many natural ponds for fish farming and irrigating water storage, covering a total area of 868 hectares together with the river. In the 1990s, the middle reaches of the Guitang River were partly straightened, resulting in the disappearance of tributaries and a severe shrinkage of the river course. Today, 84% of its catchment area has been occupied with urban development, which leads to obvious changes in the structure of upstream farmlands and drastic or complete changes of land use in other reaches, significantly erasing the hydrological characteristics of the river (Fig. 2).



- 公园绿地
Parks
- 道路绿地和功能绿地
Road green space and functional green space
- 植被覆盖状态较好的山体
Mountains with sound vegetation cover
- 水田
Paddy field
- 河流
River

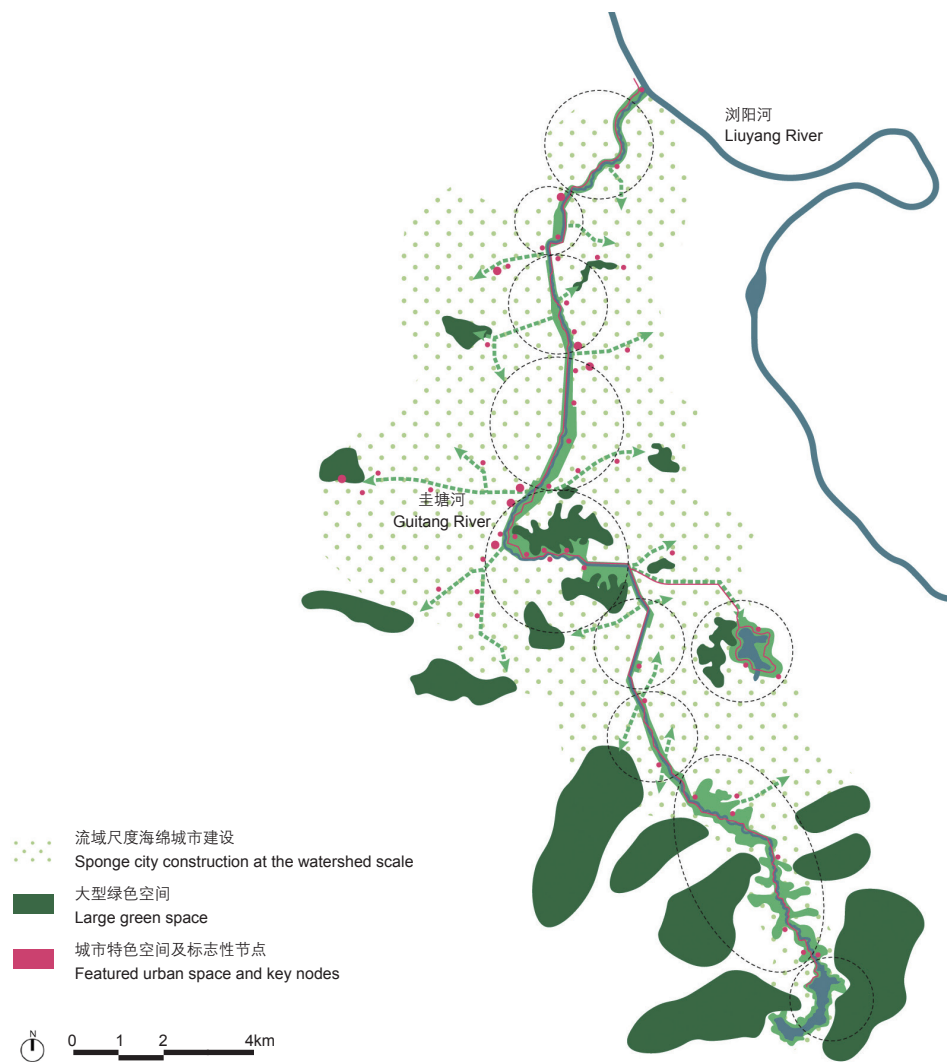


- 主干道周边商业、行政和公共功能集中区
Hubs of commercial, administrative, and public functions along main roads
- 重要节点 (商业和行政服务集中区)
Important node (hubs of commercial and administrative services)
- 重要节点 (公共设施和集中教育区)
Important node (hubs of public facilities and educational opportunities)
- 重要节点 (商业和工业集中区)
Important node (hubs of commercial and industrial functions)
- 重要节点 (绿色生态集中区)
Important node (hubs of ecological green space)
- 主干道
Main road
- 地铁线路
Subway
- 地铁站 (辐射范围500m)
Subway station (with a service radius of 500 m)
- 铁路轨道
Railway
- 旅游热门地点
Hot tourist destination

8. 圭塘河流域绿地类型
9. 圭塘河流域及周边区域功能结构分析图
10. 在流域内推行海绵城市建设理念, 绿地空间同生态廊道连接形成蓝绿生态网络。

8. Green space types of the Guitang River watershed
9. Functional structure analysis of areas in and around the Guitang River watershed

10. Sponge city construction is carried out in the watershed, while the green spaces are connected with eco-corridors to form a blue and green ecological network.



With only two small upstream reservoirs whose total catchment area are about 4 km², the lower reaches of Guitang River is suffering from a shortage of water supply, which has been even aggravated by tourism development projects near the reservoirs. Meanwhile, the channelized banks cut off the natural exchange of surface and underground water in the watershed, causing a shrinkage of ecological baseflow in the river, which is mainly kept by water discharged from sewage treatment plants in dry seasons. The massive impervious surfaces and loss of space for stormwater retention result in a higher frequency of urban waterlogging and keep raising the highest flood water level record. The water pollutants in the Guitang River watershed mainly come from the combined drainage system, where the rainwater gets mixed by sewage and then directly

discharged into the river, together with the tailing-water, non-point agricultural pollutants, and wastes from the slaughter houses and outdoor markets along the river. In light of water ecology, the flat, straight, and hardened water course sees a degradation in natural structure and biodiversity, and facilities such as weirs also break the ecological connectivity of the river. In addition, riverside express lanes separate the city from the river, discouraging citizens accessing the waterside. In a sense, the Guitang River has become a barrier to Changsha's urban development (Fig. 3).

3 Restoration and Management Planning of the Guitang River at the Watershed Scale

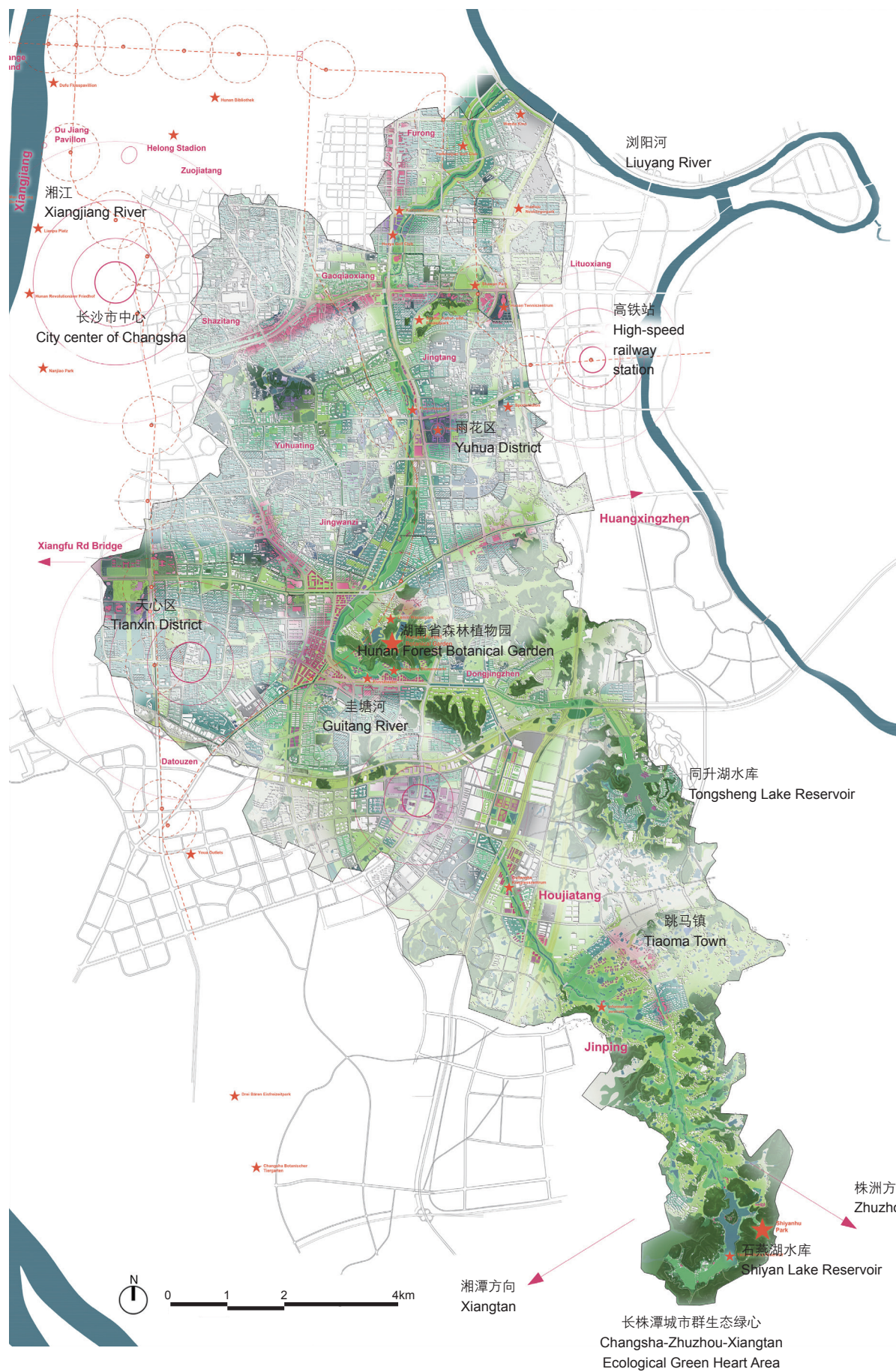
3.1 Design Objectives

Through nature-based solutions, the design team hopes to restore the natural water circulation and form a sustainable operation mechanism for water ecosystem across the Changsha City. Specific measures include reshaping the natural pattern of the Guitang River to prevent flooding and waterlogging and maintain the ecological baseflow for the river; optimizing land use and cover patterns in the watershed through sponge city construction and river restoration; integrating ecological treatment facilities and formulating higher discharge standards for sewage treatment plants to improve the water quality and finally restore the ecosystem of the watershed.

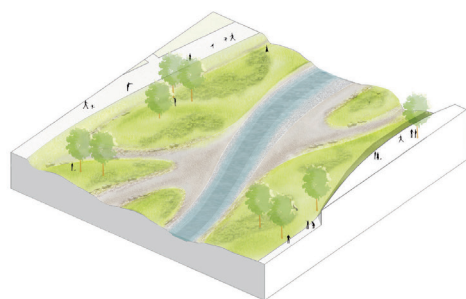
The planning and design of the Guitang River watershed requires the cooperation of multiple fields including urban planning and design, landscape architecture, ecological restoration, and hydraulic engineering. First, a coordinated planning at the watershed scale is needed to combine the river ecosystem restoration with the holistic development of Changsha, to come to a cross-scale planning and design from the watershed scale to the river scale. Then, some site-scale projects along the river would be proposed, such as the Jingtang Sponge City Demonstration Park, to promote the city's industrial transformation and upgradation. Such a multi-scaled approach can not only improve the river's environment, but also explore its more ecological potentials to help build a social-economic-natural compound ecosystem (Fig. 4).

3.2 The Design Process — Mathematical Models Assisted Planning and Design

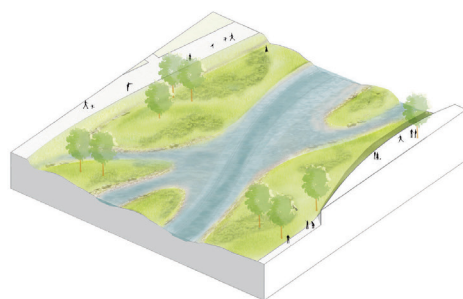
The project involves different systems including the whole water system of the Guitang River, the urban drainage system, and the sponge city system, and requires coordination of different disciplines, implying multiple and complex factors



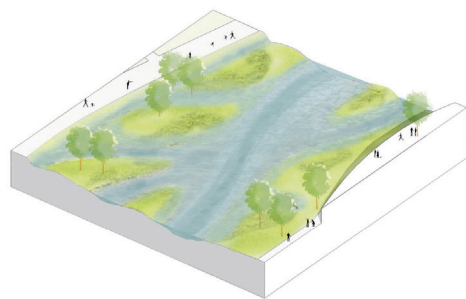
- 枯水流槽
Channel for the dry season
- 百年一遇洪水水位线
100-year flood water level
- 近水生态绿地：河岸公园和生态廊道
Riparian green space: riverfront park and eco-corridor
- 近水生态绿地：社区绿地、运动场和绿色屋顶
Riparian green space: green space in community, sports ground, and green roof
- 自然河床（常淹没区）
Nature riverbed (as frequently flooded area)
- 其他绿地
Other green space
- 公共空间和城市广场
Public space and urban square
- 生态净化设施
Ecological purification facilities
- 植被覆盖状态较好的山体
Mountains with sound vegetation cover
- 近水步行道和自行车道
Riparian promenade and bike lane
- 新建发展区域
New development area
- 核心区域
Core area
- 重要节点（商业和行政服务集中区）
Important node (hubs of commercial and administrative services)
- 重要节点（公共设施和集中区）
Important node (hubs of public facilities and education)
- 地铁线路
Subway
- U 地铁站（辐射范围500m）
Subway station (with a service radius of 500 m)
- 旅游热门地点
Hot tourist destination
- 重要节点（商业和行政服务集中区、办公区和旅游区）
Important node (hubs of commercial and administrative services, office area, and tourist area)
- 重要节点（文化和公共设施集中区）
Important node (hubs of cultural services and public facilities)



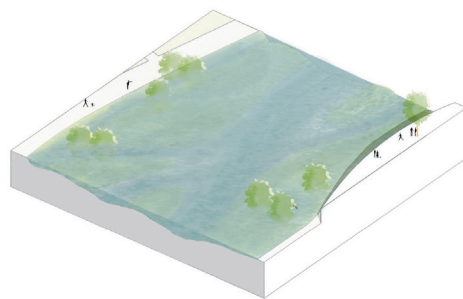
枯水期水位
Water level in dry seasons



一年多次丰水位
Water level in rainy seasons



半年一次洪水位
Water level of half-a-year flooding



两年一次洪水位
Water level of 2-year flooding

11. 蓝绿生态网络与城市现状及规划相结合
12. 不同降雨工况下圭塘河水位与河岸的关系
11. The blue and green ecological network combined with the existing and planned urban development of the city
12. The water levels in different rainfall scenarios.

and interactions to be considered. Therefore, four coupling mathematical models were employed to find a scheme that coordinates the watershed treatment performance with socio-economic benefits: a hydrodynamic model of water systems, a water quality model, a hydrodynamic model of drainage networks, and a hydrological model of watersheds (Fig. 5).

The hydrodynamic model of water systems can simulate the characteristics of many ecological elements, such as the shape and slope of the main channel in the dry season, the area of shallow water and wetlands, and materials for ecological revetment, as well as their states under different flooding scenarios, which are all important references for the flood control and ecological restoration design of the river. In this project, a hydrodynamic model of the current water system of the Guitang River was first built up, and calibrated and validated with data on actual precipitation and measurements of the river till the model's reliability was high enough. Then the model was used to simulate a 100-year flood to find out how to improve the current embankments of the river: in the upstream farmlands, arrange space for water retention depending on the current terrain; in the urban area in middle and lower reaches, enlarge the size of the cross section and replace the impervious

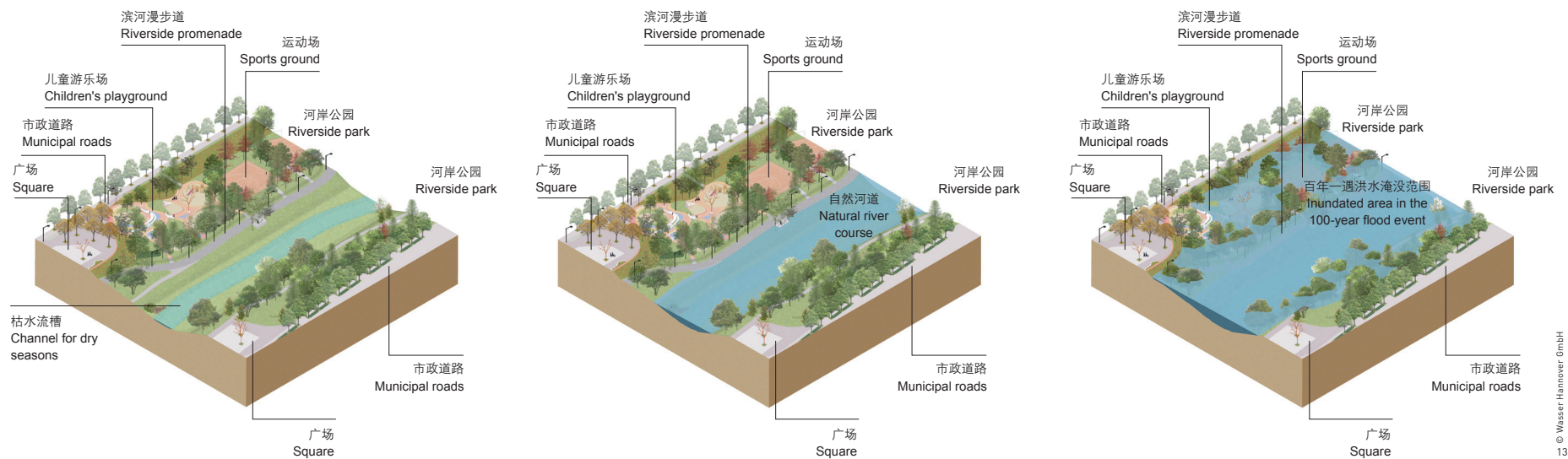
shorelines with diverse ecological ones according to different water levels. Afterwards, the water level, flow speed, and erosion of the banks and riverbed in 2-, 10-, 20-, 50-, and 100-year floods, with these measures implemented, were respectively simulated as the basis for further design. The water level simulations helped the riparian landscape and flood control design, and indicated the influence on rainwater outlets along the river in different precipitation scenarios. The simulations of erosion effects caused by floods with different flow speeds can guide the selection of suitable ecological measures and materials to prevent the river banks from inadequate or excessive construction and allocate investment properly (Fig. 6).

The water quality model, the hydrodynamic model of drainage networks, and the hydrological model of watersheds were coupled (all checked and calibrated) to simulate the status quo and treatment scenarios of the watershed. First, with the water quality model, this project determined the pollution load capacity of the Guitang River, discovered that its largest pollution source was the urban drainage system by the hydrological model of watersheds, and identified the areas vulnerable to waterlogging through simulation by the hydrodynamic model of drainage networks. These results suggested an optimization of the urban drainage network including a planning of rain and sewage diversion (Fig. 7), a blue and green ecological corridor planning determining the channels for draining excessive rainwater based on terrain analysis, and a terminal pollutant-intercept system consisting of sedimentation / overflow ponds, and eco-filters at outlets to purify the rainwater before it is discharged into the river. However, a second watershed hydrological simulation showed that only with these measures, the water quality of the Guitang River may not reach the standard totally. Thus, a source control approach should be added through sponge city construction at the neighborhood scale. Finally, the effectiveness and feasibility of all these measures were tested again with the water quality model. In the process of iterative argumentation and adjustment of the design and modeling, the cost-benefit performances of many different solution arrangements have been quantified and compared to find out the most appropriate one for the Guitang River watershed.

3.3 Planning and Design Scheme

3.3.1 The Blue and Green Ecological Network Combined with Urban Functional Zoning

A blue and green ecological network is proposed to integrate the forest conservation sites green patches south to the watershed (e.g., the Changsha-Zhuzhou-Xiangtan Ecological



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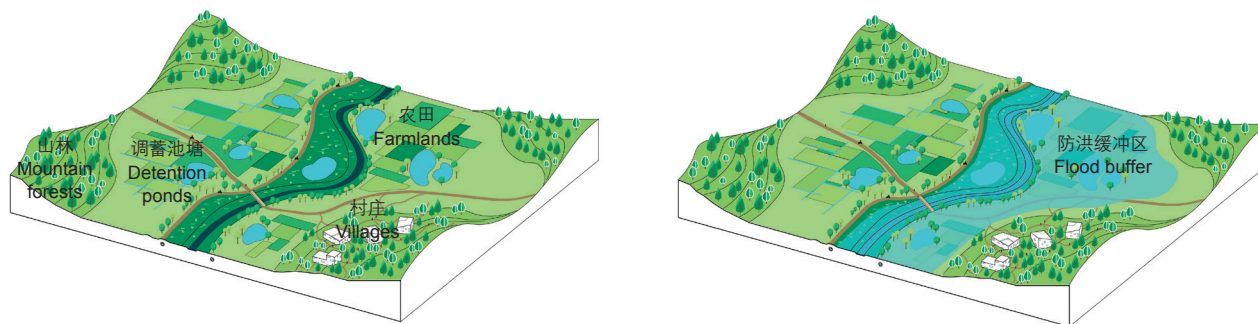
Green Heart Area), the urban woodlands (e.g., the Hunan Forest Botanical Garden), and some green patches (e.g., the linear Liuyang River Ecological Corridor) (Fig. 8). On this basis, according to various hydrologic characteristics, functions, and urban development demands along different segments of the river (Fig. 9), specific watershed management strategies, ecological restoration objectives, and urban development agendas (Fig. 10, 11) could be determined. For instance, to set aside floodwater storage space, connect ponds network, and develop tourist destinations in the upstream agricultural area; to implement serves to water pollution control and urban function integration around the middle reach; and to conduct sedimentation management and flood control in the lower reach.

This ecological network, coordinated deeply with the urban development, will bring significant improvement for the ecological environment of the Guitang River, both in riparian landscape and recreational space. The resulting land appreciation and living quality improvement would promote the industrial upgradation along the Guitang River.

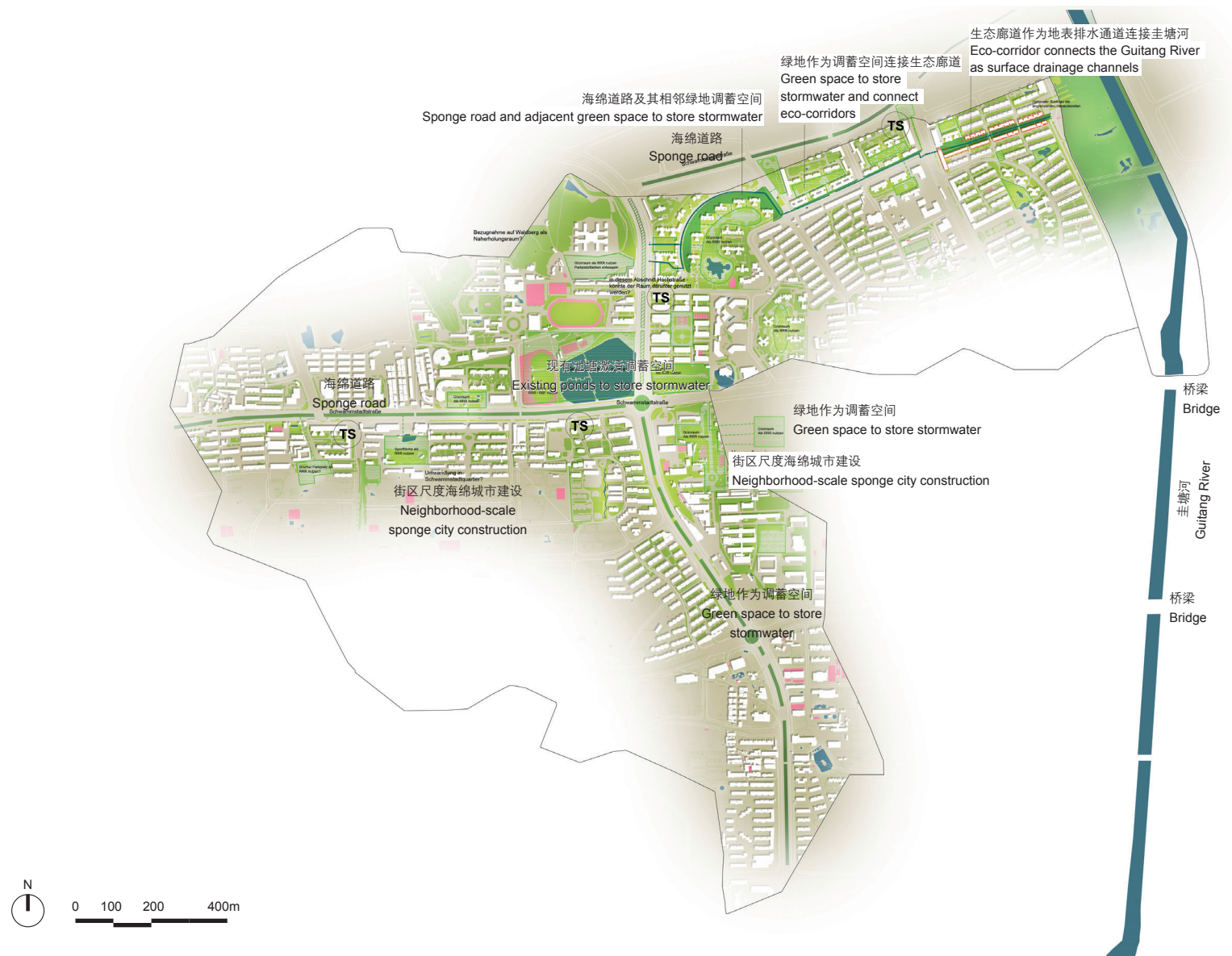
3.3.2 Natural River Restoration

The calculation results based on the handbook for rain storm calculation and verified by modeling shows that the Guitang River watershed sees a dramatic variation in the runoff flow. For example, the peak flow of the estuary in a 100-year flood is about $604 \text{ m}^3/\text{s}$, while that in a 2-year flood is $118 \text{ m}^3/\text{s}$, and in the dry season $1.1 \text{ m}^3/\text{s}$. Thus, with the hydrodynamic model of water systems, it is necessary to simulate the water levels, flow speeds, and erosion effects on the river bank caused under three scenarios of non-precipitation baseflow, normal rainfall drainage, and flood discharge, for which the project team proposed respective strategies of employing a narrower channel in the dry season, restoring the natural river, and widening the flood discharge channel, each with suitable revetment materials and aquatic plants. To be specific, the narrower channel constructed in the river could rise the water level during the dry season, shaping a meandering river course with ponds and shoals to create diverse habitats for animals and plants and a self-purifying water environment; some riparian parks or green space can be temperately flooded to increase the flood storage capacity of the river (Fig. 12).

13. 枯水期的河道流槽，市民活动可延伸至自然河道范围内（左）；两年一遇丰水状态下，滨水慢行道仍然可使用（中）；百年一遇洪水状态下，河岸公园转变为调蓄行洪空间（右）。
14. 在上游城郊区域的河道两岸规划可淹没的农田与调蓄池塘（左）；当洪涝发生时作为大范围的调蓄空间，减少下游洪水威胁（右）。
13. In dry seasons, the natural river course can accommodate citizens' recreational activities (left); in the high-water period with a 2-year rainfall event, the riverside promenade can still be used (middle); in a 100-year flood, the riverside parks can store floodwater temporarily (right).
14. To plan floodable farmlands and storage ponds in the upper reaches of the river (left) to reduce the flooding risk downstream during when necessary (right).



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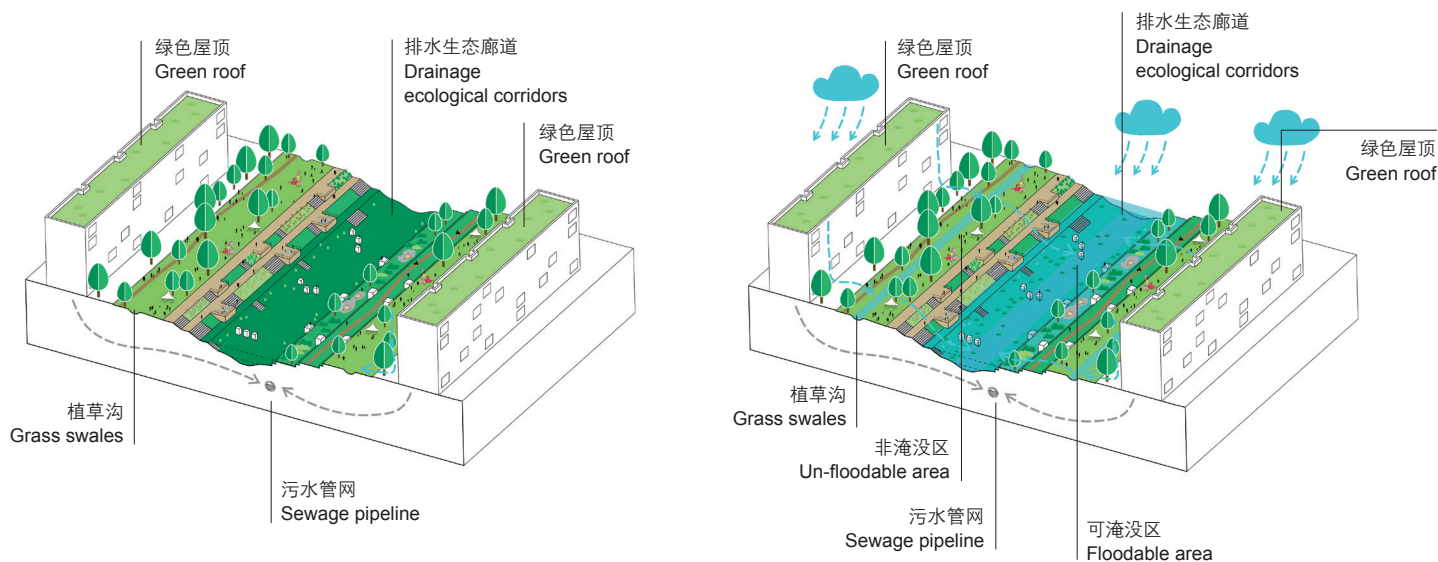
15. 圭塘河下游段可恢复为生态廊道。
15. The downstream of the Guitang River can be restored as an ecological corridor.

3.3.3 Riparian Space Improvement

The riparian space improvement at the middle and lower reaches of the Guitang River should respond to both ecological and social requirements, most of which are to be set in areas lower than the flood control level such as promenades, recreational facilities, water treatment facilities, and flood discharge channels. Therefore, the project adopts a resilient approach in horizontal and vertical designing based on the simulated results of the hydrodynamic models. For example, the frequently used squares and municipal roads are set higher than the 100-year flood water level; children's playground between the 100- and 50-year flood water levels; temporary spaces for flood discharge or retention like waterscape sites and

sports grounds between the 50- and 20-year levels; and riverside promenades slightly higher than the 5- or 2-year level to be frequently flooded (Fig. 13). Besides, water treatment facilities, such as sedimentation ponds and eco-filters to reduce pollution from combined drainage systems, should also be planned in combination with the riparian spaces, and the purified water could recharge the river directly.

For the farmland area in the upper reach, the hydrological conditions could be improved through the adjustment in land use. For instance, the river valley could serve as temporary flood retention areas with flood-resistant crops. The ponds in the upstream mountains may also be used for stormwater storage to slow down the confluent speed (Fig. 14).



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3.3.4 Watershed-Scale Ecological Corridor Construction

To realize a more natural water circulation in the city, a watershed-scale ecological corridor is to be constructed with sound investigation of the watershed's historical hydrologic data, topography, existing green spaces, land use planning, and the urban renewal requirements. Such an ecological corridor means not only to connect existing green spaces or improve the water system within individual parcels, but also to take full advantage of the urban renewal agenda and the blue and green ecological network at a larger scale.

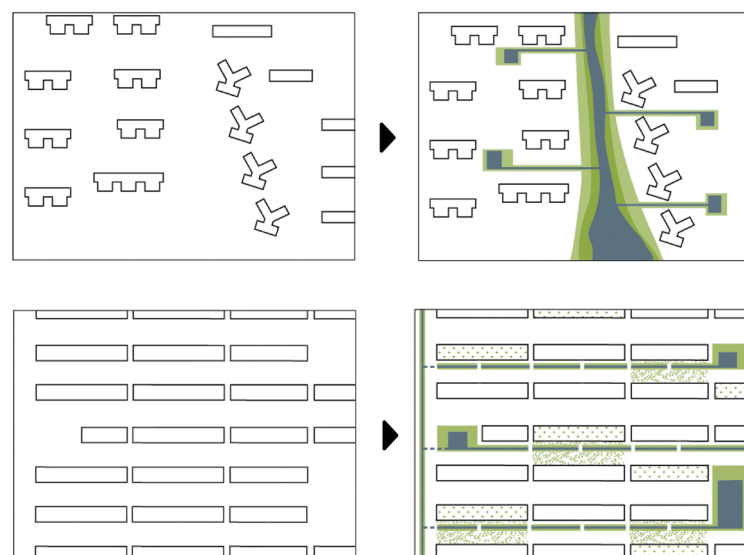
The ecological corridor could connect the green nodes, the urban built area, and the main course of the Guitang River, and provide a drainage channel for excessive rainwater. It links the individual habitat patches for living creatures while bridges the urban open spaces and riparian spaces for citizens (Fig. 15). Another function of the corridor lies in collecting the purified rainwater from the sponge city structures to recharge both the groundwater and the ecological base flow of the Guitang River. When there is a heavy rainfall, the corridor can convey the surface runoff from the urban area into the river to relieve waterlogging (Fig. 16). On this basis, the landscape design for the ecological corridor should fully consider its seasonal and occasional variation of water volume.

3.3.5 Neighborhood-Scale Sponge City Construction

Neighborhood-scale sponge city structures, either distributed or semi-distributed, are “capillaries” in the watershed-scale ecological corridor. Their selection and arrangement should consider the impervious degree of certain urban areas, as well as

a holistic view integrating the urban-scale drainage system, the watershed-scale ecological corridor, and the Guitang River, to generate specific solutions for different assisted by the watershed hydrological model (Fig. 17).

In practical planning, existing ponds should be reserved as much as possible to keep the natural hydrological circulation. With the sponge city structures, it is expected to realize a storage and retention for 30 mm precipitation, an outflow control of 10 L/(s·hm²), and runoff purification for no less than 50 percent of all the hardened surfaces. Considering the financial feasibility,



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16. 生态廊道设计形式范例。左图为非降雨期状态，右图为降雨期状态，廊道内可形成地表排水通道。
17. 呈分散式建筑群中的海绵城市建设措施在城市建成区内的不同布置形式：分散式（上）与平行式（下）。
18. 井塘海绵城市示范公园效果图
16. An example of the ecological corridor design pattern in dry seasons (left) and rainy seasons when the surface drainage paths form (right).
17. Different sponge city structure layouts in the built urban area: disturbed (above) and parallel (below).
18. A rendering of the Jingtang Sponge City Demonstration Park

these goals could compromise to a certain degree to save cost if there is no water body on-hand to use in the built urban area.

4 Conclusions

The so-called comprehensive watershed management in many cities has been long confronting with problems such as ambiguous technical standards, insufficient interdisciplinary collaboration, poor construction management, neglect on the ecological functions of rivers, image-orientated concepts, as well as frequently altered plans. Such practices not only put extra pressure to local finance and land use, but also cause government credit risk.

The practice of the Guitang River watershed management and ecological restoration planning and design indicates the significant integrity and complexity throughout the establishment of a natural ecosystem and its coupling with urban socio-economic ecosystems, which requires trans-disciplinary collaboration, overall consideration of varied targets and stakeholders, and rational analyses of the interactions between diverse ecological elements to reach a sustainable solutions. Currently, most pollutant-intercepting facilities have been equipped, some riparian parks are built up, and a demonstration park for Jingtang sponge city construction has just launched (Fig. 18). This overall planning of the Guitang River watershed will also support the

regional regulatory planning, river system planning, rainwater discharge and flood control planning, and the study of sponge city construction index system, and serve as principles for the following urban development and riverbank improvement at the watershed scale. Moreover, the overall planning could contribute to systematic technical roadmap, short-term and long-term agendas, and guarantee measures to regulate the development, transformation, treatment and management of each river. **LAF**

PROJECT INFORMATION

Location: Changsha City, Hu'nan Province, China
Area (size): 108.6 km²
Client: Changsha Guitang River Catchment Development and Construction Co., Ltd.
Project Design: Wasser Hannover GmbH
Chief Designers: Peng Chiyan, Oliver Seidel, Ralf Diekmann, Jens Meisel, Joachim Bengsch
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Project Team: Liu Yuan, Wang Run, Zheng Nengshi, Oliver Seidel, Tim Mohr, Holger Pabsch, Joachim Bengsch, Lutz Evers, Christian Bouillon, Zhou Meiyue, Tang Shutian, Andreas Tangen, Li Honghao, Richard Rohlfing, Lennart Wedekind, Uwe Klaus, Zhu Limin, Zhang Zhineng, Wu Kai, Chen Shaowei, Axel Hermening, Xu Chijun
Design Period: 2017 - 2019

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