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国土空间规划下的流域生态规划思考

THOUGHTS ON ECOLOGICAL WATERSHED PLANNING UNDER THE TERRITORIAL SPATIAL PLANNING

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摘要

笔者首先提出了当前国内流域普遍存在的问题，指出流域生态规划对于多学科协同的迫切需求，并从流域水系规划、自然河流与湿地保护、河流与湿地的生态基流恢复、面源污染削减、生物多样性保护几个方面阐述了流域生态规划的理念与实践。笔者认为，如果利用好国土空间规划重新编制之机，通过多学科协同，在国土空间规划时预留出多功能生态空间，可有效实现防洪排涝、水质提升、生态基流保障、生物多样性保护等目标。在这一综合性解决方案中，只有在规划层面进行协同，将地上地下、上游下游、河岸等在空间及时间维度上进行统筹兼顾，才能将多种生态功能进行整合，使之在同一土地空间内发挥多重生态效益。最后，笔者提出，规划设计师有能力统筹各个专业解决各种生态问题，而实现这一愿景的前提是在新的国土空间规划中将城市总体规划与流域生态规划相结合。

关键词

流域生态规划；协同规划；跨学科协作；国土空间规划；生态廊道

ABSTRACT

The author firstly points out several problems that commonly exist in China's watersheds and the urgent need for multidisciplinary collaboration in ecological planning. The theories and practices on watershed ecological planning are reviewed respectively from the aspects of waterway planning, natural river and wetland protection, ecological baseflow recovery, nonpoint source pollution reduction, and biodiversity protection. The author suggests that if we could reserve multi-functional ecological zone in the new territorial spatial planning by multidisciplinary collaboration, ecological goals including flood control, water quality improvement, ecological base flow provision, and biodiversity protection could be achieved. In this comprehensive solution, only when water bodies and associated habitats such as the ground and underground, upstream and downstream, and rivers and banks are coordinated as a whole, it will generate multiple ecological benefits. Finally, the author believes that planners and designers have the ability to solve ecological problems. To fulfill this vision, we must call for collaboration between land planning and ecological watershed planning in the process of territorial spatial planning.

KEYWORDS

Ecological Watershed Planning; Collaborative Planning; Cross-Disciplinary Collaboration; Territorial Spatial Planning; Ecological Corridor

1 中国的流域生态问题及生态规划的协同需求

随着城镇化的不断推进，中国的环境问题日益突出。尽管中央政府已在过去几年内要求各地方政府开展水环境治理工作，但在调研了全国几十个河流治理项目之后，笔者发现，国内流域普遍存在以下问题：1）河流水质差，点源和面源（特别是农业面源）污染严重；2）自然河流逐渐被改造为以防洪排涝为主的水利工程；3）河流的生态基流保障程度低；4）河道及泛洪平原内存在基本农田；5）河流的生态廊道功能脆弱；6）河流防洪标准普遍偏低，与规范要求存在一定距离；7）众多沿河、沿海滩涂被开发，流域内的湿地逐渐减少。

在规划实践中，很多生态用地均具有多功能性，譬如河流廊道具有防洪、提升水质、增加生物多样性、提供游憩服务等多种功能。在规划时，应先量化河流缓冲带、湿地，以及土壤等自然要素的生态系

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EDITED BY TIAN Xiaojie **TRANSLATED BY** XIAO Jie Tina TIAN

统服务所需的土地，再决定非建设用地的布局和面积，进而确定城市建设用地边界。然而，目前的国土空间规划编制通常基于土地指标，特别是对耕地及建设用地指标进行管控。国土空间规划中与生态相关联的地表水系统、地下水系统、森林系统、生物多样性系统等的管理分散在水利部、自然资源部、生态环境部等不同部门，导致山、水、林、田、湖、草各个系统未实现协同，有时甚至会发生冲突。

针对上述现状，笔者尝试在规划设计过程中提出综合性解决方案，并希望这些思考能为在国土空间规划层面优化流域生态提供思路。

2 基于国土空间规划与多学科协同的流域生态规划

流域生态规划的核心是构建人与自然和谐相处、不同土地利用类型协同集约开发的流域和山水廊道空间。从以防洪排涝为优先的水环境规划，到生物多样性规划，到兼顾人类游憩和城市发展需求的土地利用规划，再到统筹经济的区域产业规划及旅游规划，通过将这些规划进行叠加，可以整合出生态优先的综合规划。这种规划方法来源于伊恩·麦克哈格《设计结合自然》一书中的思想，以及对城市和环境在时间维度上变迁的推演。综合规划涉及的学科及专业包括地质学、水文学、水利工程、给排水科学与工程、水土保持、景观设计、城乡规划、旅游管理、经济学等。在进行国土空间规划时，需要各个学科和专业分步骤地进行协同，从而将地上地下、上游下游、河流河岸等在物质空间及时间维度上进行统筹规划。其中，土地利用规划及发展规划的基础是流域生态规划，而流域生态规划的基础是流域水系规划。流域生态规划还包括地形、坡度、地质灾害、植被类型、森林覆盖率、动植物保护、通风走廊、热岛效应消减、水土保持等方面。

本文主要从流域水系规划（首要为防洪）、自然河流与湿地保护、河流与湿地的生态基流恢复、面源污染削减、生物多样性保护方面来阐述流域生态规划的理念与实践。

2.1 流域水系规划是流域生态规划的基础

流域生态规划需要首先开展流域水系规划，流域水系规划应首先解决防洪问题，并在满足防洪计算的同时考虑生态效益。在防洪方面，需要以流域为单位进行规划，在整个流域内分散建设防洪基础设施，从而减轻河道本身的防洪压力。防洪排涝不仅要利用工程措施，还需要采取非工程措施，即通过扩大河流断面增加河道的排洪能力。国际上也在积极推行非工程性防洪措施，主要包括以下三类规划措施：

第一，保证河流廊道的宽度和过水断面的面积。河流廊道存在多种定义，此处指常水位之外的河岸空间。水文工程研究表明，较为理

1 Ecological Problems in China's Watersheds and Needs for Collaborative Ecological Planning

During the urbanization in China, the number of environmental concerns continues increasing. Over the past few years, local governments have been required to carry out water environmental remediation. Nonetheless, after investigating a great number of remediation projects nationwide, the author summarized the problems commonly exist in China's watersheds, including: 1) the water quality of rivers is poor, with heavy point and nonpoint (particularly agriculture-related) source pollution; 2) more and more natural rivers are being transformed into hydraulic facilitates for flooding control; 3) the ecological base flow of rivers is degrading; 4) basic farmlands are found in watercourses and flood plains that are not supposed to; 5) more and more rivers no longer serve as ecological corridors; 6) the flood prevention standards of rivers fall behind the requirements; and 7) riparian mudflats and coastlines have been extensively developed, reducing wetlands in number and area.

In the practice of planning, ecological areas often provide multiple services. For instance, the riparian corridors could provide services like flood prevention, water quality and biodiversity improvement, and recreational opportunities. In addition, only after quantifying the ecosystem services of natural elements such as river buffer zones, wetlands, and soil, can we determine the layout and size of non-development (or protected) land and then the boundaries of urban development. However, China's current territorial spatial planning usually prioritizes traditional land use demands, especially arable and development lands; the surface and underground water systems, forests, and biodiversity are jointly managed by the Ministries of Water Resources, Natural Resources, Ecology and Environment, etc., where administrative overlaps, coordination deficiency, or interest conflicts have led to the failure to establish an integrated management of ecosystems such as mountains, water bodies, forests, farmlands, lake, and grasslands.

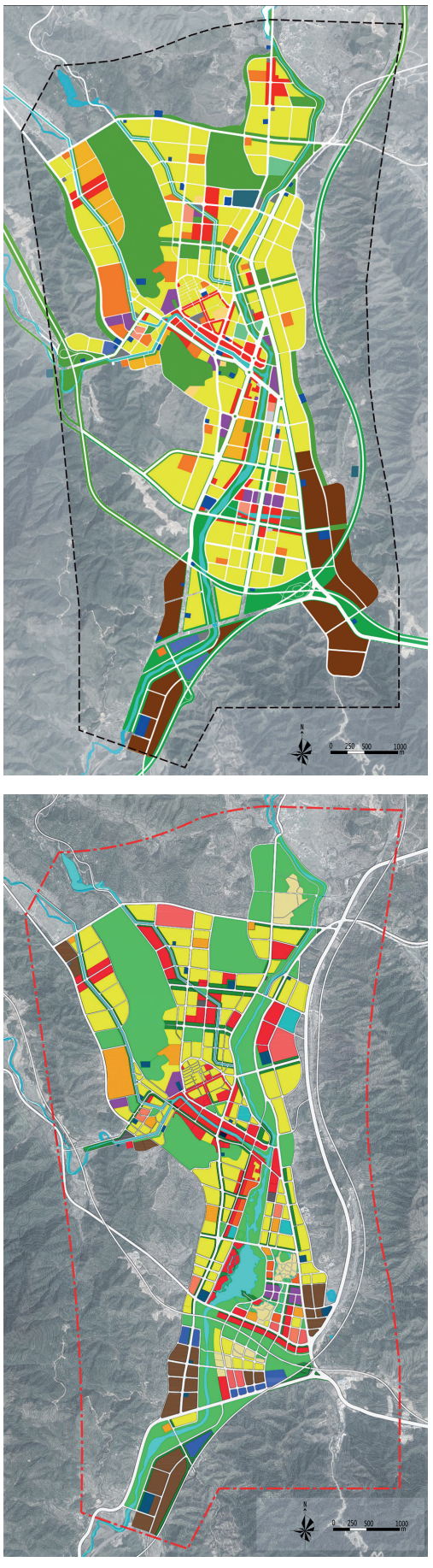
As a response, the author here proposes a comprehensive solution for China's watershed planning and design practices, offering ideas for the improvement of watershed ecology at the level of territorial spatial planning.

2 Ecological Watershed Planning Based on Territorial Spatial Planning and Cross-Disciplinary Collaboration

Essentially, ecological watershed planning is to build watersheds and corridors where human and the nature live

1. 上图为连平县城原有土地利用规划。连平县城绿地严重不足，原有规划河道狭窄，防洪能力未达到50年一遇标准，使其邻近的105国道面临洪涝风险；下图为连平县城修订后土地利用规划。方案建议将沿河建设用地改为非建设用地，增加河流廊道宽度，提高防洪能力，增加生态绿地及休闲空间，尽可能地恢复河流的生态功能。

1. The original land use plan of Lianping County (above) shows that the green space in Lianping County was seriously inadequate while the planned river courses were too narrow to withstand 50-year floods, bringing flooding risk to 105 National Highway passing by. The revised land use plan of Lianping County (below) changes the development lands along the river into non-development ones, widens the riparian corridor to improve the flood control capacity, and increases green and recreational spaces to restore the ecological functions of the river as much as possible.



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in harmony and various land uses are intensively and collaboratively planned. Adopted the ideas from *Design with Nature* by Ian McHarg, while considering the changes of city and environment over time, an ecology-prioritized comprehensive planning can be derived by overlapping various subject plans for flood control, biodiversity protection, recreational improvement, urban development, regional industrial and tourism growth, etc. Such a comprehensive planning requires disciplinary knowledge and specialties from Geology, Hydrology, Hydraulic Engineering, Water Supply and Drainage, Water and Soil Conservation, Landscape Architecture, Urban and Rural Planning, Tourism Management, Economics, etc., to develop a synergic, time-phased spatial plan for the entire watershed. To professionals, it is important to realize that waterway planning is the basis for ecological watershed planning, which further defines the corresponding land use and urban development planning. In ecological watershed planning, factors to be considered including terrain, slope, geological disaster risk, vegetation type, forest coverage, flora and fauna protection, ventilation corridor, reduction of heat island effect, and water and soil conservation.

This article will introduce the theories and practices of ecological watershed planning in aspects of waterway planning (mainly for flooding control), natural river and wetland protection, ecological base flow restoration of rivers and wetlands, nonpoint source pollution reduction, and biodiversity protection.

2.1 Waterway Planning — The Basis of Ecological Watershed Planning

As a foundation of ecological watershed planning, waterway planning is expected to primarily meet flooding control requirements (based on hydraulic calculation) while maximizing ecological benefits. The planning should consider watershed as a whole and distribute flooding control infrastructures dispersedly to reduce the discharge pressure of river courses. Flooding control requires not only engineering approaches but also non-engineering ones that can help enlarge the cross section of rivers to enhance drainage capacity. The following non-engineering measures are widely applied worldwide:

First, widening riparian corridor and cross section. The definitions of riparian corridor vary. In this article, it refers to the riverside areas at ordinary water level. According to exiting hydraulic engineering studies, the

想的河流廊道宽度为可抵御百年一遇洪水的过水断面宽度[1]。鉴于河流两岸的农业活动及城镇开发需求，建议五、六级河流单侧河岸预留100~300m宽的廊道，四级河流预留60~200m宽的廊道，三级河流预留30~100m宽的廊道，一、二级河流预留15~50m宽的廊道①。在城市核心地段，局部或单侧河流廊道的宽度可以有所缩窄，以增加城市亲水空间。增大河流廊道宽度可增加过水断面的面积，同时保护河岸植被。例如，广东省连平河项目即通过流域水系规划增加了河流廊道宽度，从而提高了河流及区域的生态效益（图1，2）。

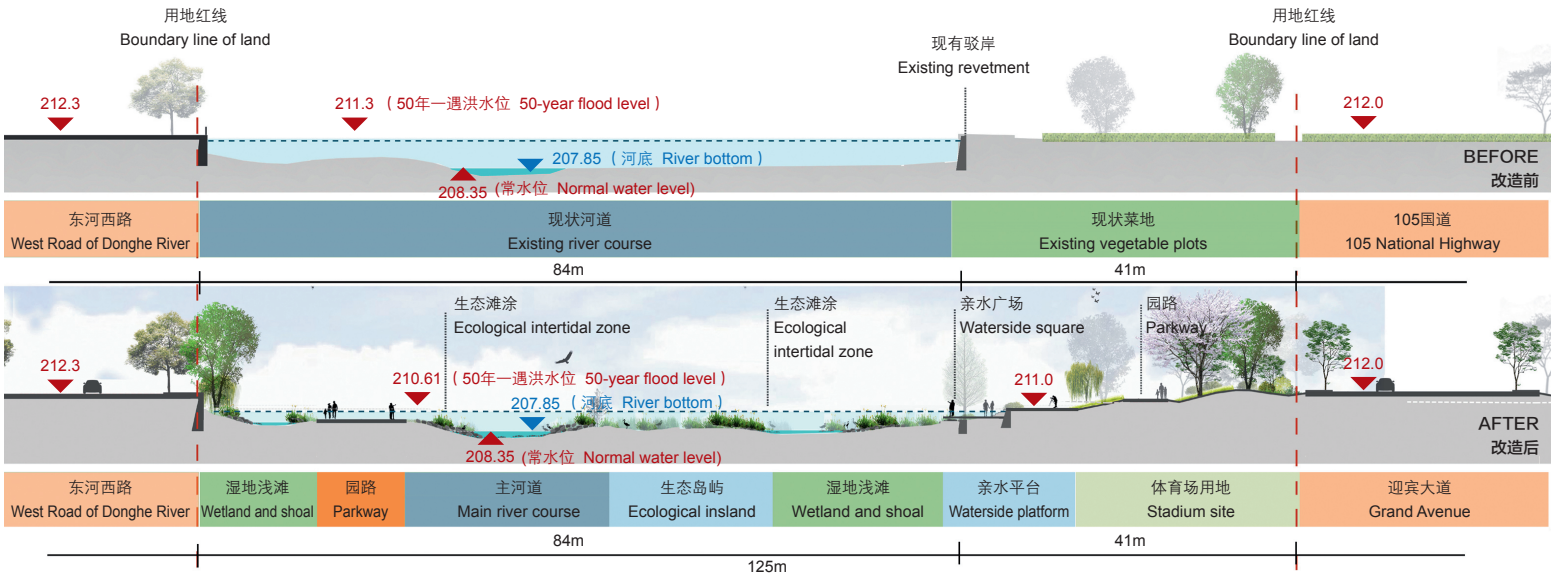
第二，在地形及土地利用规划允许的前提下，河流两侧及交汇节点应尽量保留或规划大型洪泛区，以满足支流在汇入主干河流前的滞洪需求。这就要求流域内的每一级河流都设置滞洪空间，并尽量避免在洪泛区内进行开发建设。若开发难以避免，则需要在开发地上游河道两侧规划大型洪泛荒地或湿地，以消减客水对城市的影响。在这种情况下，河流廊道或需加宽作为大型蓄滞洪公园，具体宽度需视场地条件进一步计算。在河流某些区段可以结合动植物栖息地、有机农场、生态旅游地等功能区块规划沿河湿地或沼泽地。

ideal width of a riparian corridor should be at least as wide as its cross section which could withstand 100-year flooding[1]. In view of farming activities and urban development, the corridor width of a fifth- or sixth-order stream on one side better be 100 ~ 300 meters; 60 ~ 200 meters for fourth-order streams; 30 ~ 100 meters for third-order streams; and 15 ~ 50 meters for first- or second-order streams.① In central urban areas, riparian corridors could be partly narrowed, or at least on one side, in order to increase accessible waterfront spaces. Widening riparian corridors not only helps increase the size of cross section, but also facilitate the protection of riparian vegetation. For example, by creating wider riparian corridors through waterway planning, the Lianping River in Guangdong Province has improved ecological performance of the river itself and regional environmental benefits (Fig. 1, 2).

Second, protecting or introducing large-scaled flooding areas along rivers or at confluence reaches if possible, so as to detain flood as much as possible within the tributaries. Detention spaces therefore should be created along all the streams and rivers within the watershed, while avoiding urban construction — in the inevitable cases, large flooding lands or wetlands should be planned in the upper reaches to alleviate the impact of floods on the city, where the riparian corridor needs to be widened as large parks with flood storage and retention functions, depending on specific conditions. In some segments, riparian wetlands or marshlands can be planned in combination with animal and plant habitats, eco-farms or eco-tourism sites.

① 本文的河流分级依据为罗纳德·L·施里夫于1966年提出的施里夫河流分级法，其规则定义为：直接发源于河源的河流等级为一级，两条河流交汇形成的河流的等级为这两条河流等级之和。

① The stream order classification in this article is proposed by Ronald L. Shreve in 1966. It defines rivers originating from the source as first-order streams, and the order of a river converging two tributaries is the summation of the two's orders.



2. 治理前后的连平河横剖面对比。治理后，河流廊道宽度及过水断面面积增加，50年一遇洪水位下降。

2. Transverse section of the Lianping River before and after the treatment project. The project increases the width of riparian corridor and the size of cross section while decreasing the 50-year flood level.

第三，保护流域内具有滞蓄洪功能的湿地和湖泊。湿地和湖泊是水资源利用、地下水补给、生物栖息地保护的重要载体。美国于1972年生效的《清洁水法案》不仅对污水排放标准进行了规定，也对整个国家的湿地进行了系统性保护，其基本政策是保持湿地总面积不变，如在建设过程中需要填埋湿地，则需要经过相关机构严格审批，并在他处重建同等或者更大面积、且具备原有湿地生态功能的补偿湿地[2]。中国湿地资源丰富，但湿地总面积在2006~2016年间减少了8.8%[3]，目前政府正在积极采取措施遏制这一趋势[4]。笔者建议在新的国土空间规划中，参考基本农田的保护方法来保护湿地，对湿地进行逐块登记，并加以系统性保护。

由于流域水系规划所需的水文数据时间跨度大且需大量计算，因此需要国土空间规划师与水利专家共同完成国土空间与流域水系规划。此外，当前中国城市的防洪排涝能力普遍偏低，在制定新的防洪排涝规划时，国土空间规划师和负责防洪规划的工程师可以结合绿地系统规划，尽量将工程性和非工程性防洪排涝方式融合。当流域水系规划涉及到多个行政区划时，则需要更高的行政层级主持全局，在理想情况下，此类规划应在省级层面开展。

2.2 保护自然河流与湿地

近年来，中国越来越多的自然河流被截弯取直，并在河流湿地和滩涂上建造平行于堤岸的水利设施。虽然这些设施一般都设有植草护坡，但其生态效益非常有限。此外，由于堤顶高于周边地面，河流两侧的雨水无法汇入河道。笔者在做河道规划调研时发现，人们普遍怀念儿时在河滩嬉水的经历，对于目前河流可达性和生态性的缺失感到遗憾。

世界自然基金会一直大力呼吁保护自然河流[5]。美国在20世纪实施了众多河道渠化工程，但在认识到自然河流的价值之后，于1968年通过了《国家野生与风景河流法》，以保护自然河流的风景、地质、鱼类和野生动植物、历史和文化等[6][7]。受保护的河流不允许进行人工干

Third, protecting wetlands and lakes for floodwater storage and retention in the watershed, as key spaces for water resource utilization, groundwater recharge, and habitat protection. In United States, the Clean Water Act taking issued in 1972 not only stipulates the standards of sewage discharge, but also systematically protects wetlands nationwide by maintaining the total area of wetlands. Any wetland filling for development is strictly consented and required to recreate a compensating wetland with the same size and ecological functions somewhere else[2]. China enjoys a rich wetland resources and has begun to strengthen wetland protection since the total wetland area has seen a reduction of 8.8% from 2006 to 2016[3][4]. In territorial spatial planning, a nationwide survey of wetlands is needed for further systematic protection, as what China has done with basic farmlands.

Waterway planning often needs to deal with massive calculation of hydraulic data in a long time span, where planning professionals and hydraulic experts should work together. Moreover, most Chinese cities are vulnerable to floods, especially due to their poor discharge capacity. Green space system planning should be combined with flood control planning to maximize the benefits of green and grey infrastructures. In the planning cases when different administrative jurisdictions are involved, a higher administrative agency, ideally a provincial one, should play the leading role in coordination.

2.2 Protection of Natural Rivers and Wetlands

In recent years, more and more natural rivers in China are canalized or cut off by water conservancy facilities built parallel with riparian wetlands and marshes, which has compromised the ecological services of natural rivers and banks that cannot be compensated by simply creating vegetated revetments. Moreover, the high dikes are adverse to stormwater discharging into the rivers. Based on an investigation of river remediation projects, the author also learned that most people cherish the high accessibility and ecological quality of natural rivers before the urbanization and have an urgent need for a restoration.

The World Wildlife Fund (WWF) has long called for natural river protection[5]. The United States has launched many river channelization projects in the 20th century; however, it soon began to protect the landscape, geology, fishes, wild animals and plants, and historical and cultural quality of natural rivers, and enacted the National Wild and Scenic Rivers Act in 1968[6][7], strictly limiting human

预，河流两岸也不允许进行开发建设。之后，加拿大、新西兰、澳大利亚等国家也相继立法保护自然河流，其中最大的挑战是土地问题，政府通常需要购得河岸土地的所有权，才能对其进行有效的保护。在我国，可以通过将自然河流保护举措纳入国土空间规划来确立其法定地位。

在国土空间规划中，需保留河道的自然流向、在河流两侧预留河道摆动空间以降低水流速度，并创造多样的生物栖息地。河道内及两侧的植被可以维持鱼类所需的低水温环境，沙洲和石滩适合鱼类产卵，枯枝可以为鱼类提供食物和栖息空间，并为鸟类提供捕鱼停留点，河道内的深浅滩可以营造具有不同水深和流速的水环境，为鱼类提供多样化的栖息空间，均需要加以保护。如果流域内存在一级河流，则河流两侧至少预留15~50m的森林缓冲带[8]，以保护重要水源地的自然生态环境。因此，在设计过程中，需要生态工程师、水文规划师、水利工程师、景观设计师共同参与，对水系中不同生境的营建进行综合考虑。

此外，河道规划设计还需考虑过水断面面积及流速的设计要求，这些数据均可用水利模型计算得到。如前所述，通过流域水系规划可实现过水断面的设计目标，而流速问题则需通过水利工程驳岸设计来解决。为了不阻断两侧河岸与河道之间的水交换，建议使用透水的生态驳岸。依据设计流速、当地可用材料及景观需求，可以选择不同的驳岸做法：当河流流速小于1m/s时，可以采用泥岸植草；当流速为1~2m/s时，可以铺设10cm深的石滩或种植垂柳（*Salix babylonica*）；当流速为2~3m/s时，可以铺设20cm深的石滩或种植茅草；当流速为3~4m/s时，可以铺设40cm深的石滩或采用铅丝石笼；当流速大于5m/s时，建议采用大型石块构筑驳岸[9]。

2.3 恢复河流与湿地的生态基流

流域内70%~80%的水资源来自上游[10]，污染物中大部分的氮、磷也来自一、二级河流[11]，因此，这些河流的生态质量是反映河流健康

intervention within the protected rivers and avoiding development on the river banks. Later, Canada, New Zealand, and Australia also issued laws on natural river protection, where the biggest difficulty lies in land tenure acquisition — governments have to purchase land tenure of the river banks and then to protect. In China, measures of natural river protection can be enforced as mandatory requirements in territorial spatial planning.

In territorial spatial planning, the orientation of natural rivers, as well as diversion plains, should be preserved to lower flow velocity and create diverse habitats. The vegetation in the river course can help maintain a low-temperature habitat for fishes; the shoals and rock beds are ideal habitats for fish spawning; dead branches not only offer food and habitats for fishes but also provide stopping places for birds during fish hunting; and mudflats create fish habitats in varied water depths and flow velocities. For the first-order streams in the watershed, a 15 ~ 50 m forest buffer should be preserved on each bank[8] so as to protect key waterhead areas. Thus, ecological engineers, hydrographic planners, hydraulic engineers, and landscape architects need to closely work with each other to develop comprehensive plans for habitat protection of the entire watershed.

Besides, river course planning should also consider the requirements of cross section in size and flow velocity that can be calculated with hydraulic simulation. The former can be realized through waterway planning approaches, while the latter should be addressed with revetment design. In order to maintain the natural water cycle between river and its banks, pervious ecological revetments are recommended. The variety of flow velocity designs, locally available materials, and landscape requirements defines the selection of revetment design methods: When the flow velocity is less than 1 m/s, mud revetment with grass is recommended; for 1 ~ 2 m/s, the banks can be paved with 10-cm-deep gravel beds or planted with willows (*Salix babylonica*); for 2 ~ 3 m/s, the depth of gravel beds can increase to 20 cm, or couchgrass can be planted; for 3 ~ 4 m/s, 40-cm-deep gravel beds or gabions can be used; and, when the flow velocity is higher than 5 m/s, rock beds would be a better choice[9].

2.3 Restoration of Ecological Base Flow of Rivers and Wetlands

70% ~ 80% of the water resource in a watershed is from the upper reaches[10], and most nitrogen and phosphorus pollutants are from the first- and second-order streams[11], of which ecological qualities are the key indicators to reflect the health level of rivers. However, in China, a number of rivers

水平的重要标志。然而，目前国内很多一、二级河流存在生态基流不足、水质污染，以及河道硬化等问题。很多河流生态补水工程都采用建设管道及泵站的方式将水资源从下游提升至上游，再通过自重流入下游；为了减少河流水量的下渗损失，有些项目甚至将河床改造为防渗硬底，严重破坏了河流的自然基底。还有一部分项目在黑臭水体治理中，借恢复生态基流之名，通过调水对污染物进行稀释，以达到水质断面监控达标的目的。

生态基流的问题难以在朝夕之间解决。短期内，建议利用地表蓄水以及经湿地净化后的污水厂尾水为河道提供生态基流；同时，在一定的污染物浓度范围内，河流本身也具备良好的自净能力。长远来看，生态基流问题还需借助规划手段解决。土地犹如一块巨大的“海绵”，不断调节着地表水与地下水之间的平衡，而流域内的森林与湿地是地下水资源补给的重要媒介[12][13]。国土空间规划师需要了解地下水文学知识，与地下水专家共同完成地下水规划：首先由地下水专家划定承压水层对应的地表区域，再由国土空间规划师对地表敏感地形及植被进行保护，以帮助地表水回充至承压层或潜水层，同时开展森林保护及复育工作，严禁污染，并对各类开发进行限定。

2.4 削减面源污染

最近几年，中国大力开展黑臭水体治理工作，通过截污控源、底泥清淤等方法在短期内提升了河流水质。然而，要想彻底改善水质，就需要解决面源污染问题，途径之一是系统实施海绵城市建设。由于海绵城市建设技术主要应对的是40mm以下的降雨[14]，因此其对水质长期改善的贡献度大于对排涝的贡献度。在消除黑臭问题后，仍然需要利用海绵城市建设技术对微污染水体进行处理，以大幅削减城市面源污染。

此外，削减农业面源污染还需在规划中预留部分河流廊道作为湿地或者缓冲带。大量研究表明，河流廊道可以有效削减进入河道的农业面源污染物[11]，甚至有案例显示，20m宽的植被缓冲带可以有效去除

are now faced with problems such as the loss of ecological base flow, water pollution, and watercourse hardening that, however, are often treated in unscientific way: In many ecological water compensation projects, the water flow cycle is maintain by pumping water from the lower reaches to the upper ones. To avoid water loss by infiltration, some natural riverbeds are capped with impermeable materials — or worse, in some projects in a name of restoring ecological base flows, pollutant concentration is thinned by transferring water to the river meet the water quality requirements at cross sections.

It is unrealistic to recover ecological base flow overnight. As short-term measures, surface water storage and wetland-purified tail water from sewage plants can be adopted to increase ecological base flow. Besides, rivers can cleanse themselves if the pollution concentration is not high. For the long run, planning approaches must be employed: land, working like a huge “sponge,” maintains the water cycle between the surface and underground, and forests and wetlands serve as major medium to recharge the groundwater[12][13]. The territorial spatial planners need to advance their knowledge about groundwater hydrology so as to better collaborate with groundwater experts: First, groundwater experts identify the surface area of confined water; then territorial spatial planners can come up with measures to protect the terrains and vegetation of sensitivity to facilitate aquifer recharge; meanwhile, efforts in forest protection and restoration, pollution control, and reduction of development impact are also needed.

2.4 Nonpoint Source Pollution Reduction

In recent years, China has devoted significant effort to remediate black and malodorous water bodies, seeing a short-term effect in water quality improvement through sewage interception, pollution control, and dredging. While, the key to a long-term success is to reduce nonpoint source pollution, where sponge city construction is proven as an ideal approach, because technically it is mainly employed to deal with the rainfall of 40 mm or less[14] that makes it play a significant role in long-term water quality improvement, rather than flood control. Besides being used to address the problem of black and malodorous water bodies, sponge city construction can also continue providing service of water pollution reduction for ordinary cases, to decrease nonpoint source pollution in urban areas.

An effective approach to decrease agriculture-related source pollution is to plan part of riparian corridors as wetlands or buffers. Studies have proven that riparian

60%以上的氮、磷和其他农业面源污染物[8]；沿河农田采用有机种植法及其他可持续耕作方法也可有效削减沿河农业污染。此类对农业污染的削减作用可以通过河岸带生态系统管理模型来量化。自然河岸的原生乔灌植被可有效地吸收溶于地下水中的氮，从而改善水质。河流中的沉水植物及附于河卵石表面的微生物膜也可以有效降低水体污染物含量。

和其他国家一样，中国也存在河道两侧征地难、修建缓冲带成本巨大的问题。如果能增加河流廊道宽度，并将这部分缓冲带规划在河流洪泛区内，则既能以非工程措施实现防洪目标，又可以显著削减农业面源污染，未来将产生巨大的生态效益。因此在河道两侧征地和租地势在必行，其中费用可以由节省出的工程施工费承担，而这需要国土空间规划以及相应政策的支持。

2.5 生物多样性保护

制定流域生物多样性保护规划可采用由理查德·T·T·福尔曼和米歇尔·戈德罗恩提出的“斑块—廊道—基质”模式，这也是目前实践中应用最广泛的景观生态理论之一[15]-[17]。其中，斑块用来涵养水源并作为动物栖息地，而栖息地保护区的面积需要能够支撑整个种群的延续，或者由多个自然斑块通过生态廊道连接成大型栖息地；生态廊道应尽可能宽且连续，小型动物需要数百米宽的廊道，大型动物则需要多条几公里甚至几十公里宽的廊道[18]；基质指流域的生态本底，包括河流的宽度、流速、沉积物、两侧植被、光照等变化，这些因素沿河流方向的变化产生了连续的生物能量流，并在不同河段形成不同的生境类型[19]。

流域生物多样性保护规划需要建立包含本土动植物物种的栖息地体系，可以考虑的栖息地类型包括山脊栖息地、高地栖息地、湿地栖息地及水生栖息地[18]。建议在每个流域内都营建若干数十到数百平方公

corridors can efficiently prevent rivers from agriculture-related nonpoint source pollutants[11]. For example, a 20-meter-wide vegetated buffer can remove over 60% of nitrogen and phosphorus, as well as other agriculture-related nonpoint source pollutants[8]. Moreover, chemical-fertilizer-free farming practices and other sustainable agricultural activities can also help reduce pollutants. The performances of all these measures can be quantified with the Riparian Ecosystem Management Model (REMM). In addition, naturally-grown native trees and shrubs on river banks can help improve water quality by absorbing nitrogen in the groundwater. Submerged plants and the microbes on the pebbles in rivers can help reduce water pollutants as well.

Like other countries, China also encounters difficulties in riparian land acquisition and huge costs to build buffer zones. For a greater ecological benefit, it is imperative to widen riparian corridors and buffers, as part of flooding areas, where measures of non-engineering flood control and reducing agriculture-related nonpoint source pollution can be combined. Part of the expense for land acquisitions or tenures can be covered by the saving from engineering budget, which requires supports from the territorial spatial planning and national policies.

2.5 Biodiversity Protection

Watershed biodiversity protection planning can adopt the classic Patch-Corridor-Matrix model proposed by Richard T. T. Forman and Michel Godron, which is one of the most widely applied theories in Landscape Ecology[15]~[17]. Patches can facilitate water conservation and serve as animal habitats. A habitat reserve should be large enough to support animal breeding of generations, or alternatively, consist of a number of small habitat patches that are connected with ecological corridors — Such ecological corridors should be as long and wide as possible: the width of the corridors for small animals can be hundreds of meters while that for the large ones can be several or dozens of kilometers[18]. The matrix of watershed itself is defined by factors like the width and flow velocity of rivers, deposit amount, vegetation on banks, sunlight, etc. The variations of these factors along the river course generate continuous bio-energy flows and form various ecological patterns in different river reaches[19].

In watershed biodiversity protection planning, the habitat system of native flora and fauna species, and the variety of habitat types (e.g., ridges, highlands, wetlands, and aquatic ones) should be taken into account[18]. It is commended that every watershed accommodates several

里的大型栖息地斑块，并与已有的或正在筹划的国家公园系统相连，以将生物多样性保护与公众休闲功能相结合，并适当开展生态教育及旅游活动。

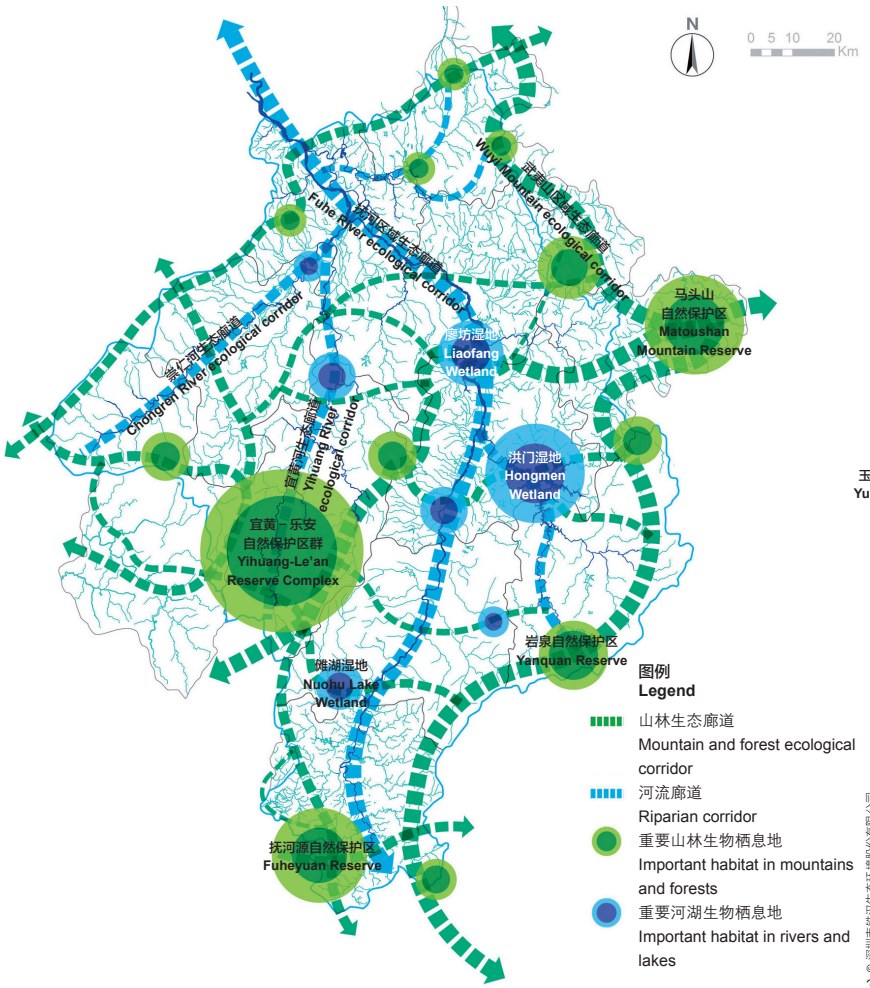
截至2018年5月，中国各类自然保护地共1.18万处（含474处自然保护区），占国土面积的18%[20]。虽然总面积很大，但很多保护地被持续增加的路网和城镇建设割裂，碎片化趋势愈加明显；同时，保护区规划的不严谨性导致很多动物处于保护区之外，更多的野生动物面临生存风险[21][22]。此外，自然保护地的管理以及保护地之间的生态廊道建设仍具有很大的提升空间，在今后的规划中应特别注意保护栖息地的完整性，并尽量在栖息地之间规划生态廊道，以将面积较小的保护地连接起来。

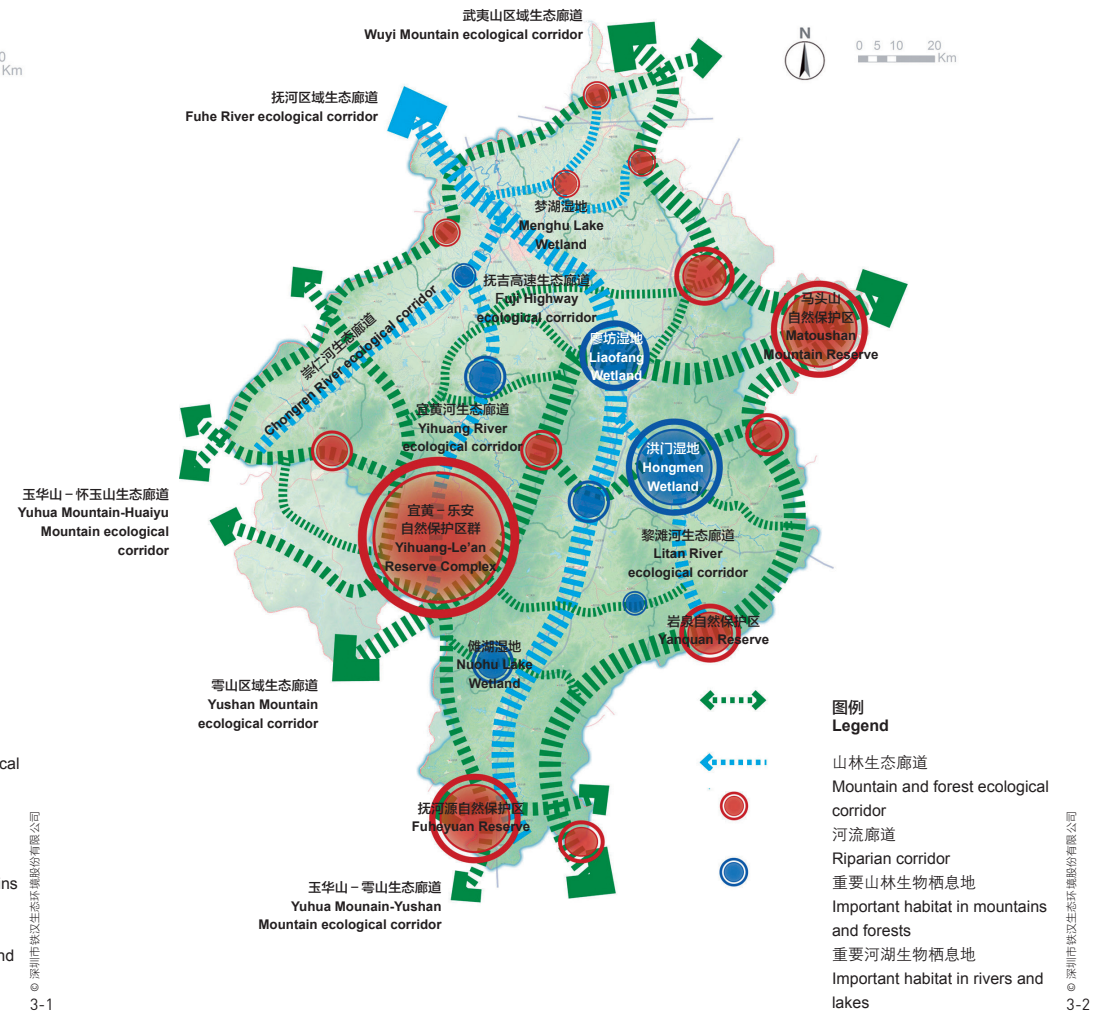
山脊廊道、河流廊道及山水之间的生态廊道可为栖息地中的动物及鸟类提供迁徙通道。河流两岸的规划设计要考虑鱼、鸟、昆虫、哺乳动物、底栖动物等的栖息需求和对廊道的宽度要求。一些生物多样性敏感区域及其廊道是国家及区域内重要物种的栖息地和基因廊道，宽度至少需达1km。当道路穿过栖息地和廊道时，要增设专供动物使用的生态桥梁和生态箱涵。在规划重要河流廊道时，建议避免在河流两侧规划连续的机动车道或自行车道，并依据指示物种确定河流廊道宽度。指示物种是对栖息地环境敏感度高的物种，如果满足了指示物种的需求，其他动物的需求就会得到满足。一般首先选择一到两种哺乳类动物（大型、小型）和两到三种鸟类（林鸟、候鸟型水鸟、留鸟型水鸟）作为指示物种，再根据场地条件和必要性选取两栖类、鱼类（以洄游性为主）和昆虫类物种。在植被规划中，要考虑植物群落的动态演替，尽量创造适宜的水文条件和地形，为植物生长提供有利条件。在流域生态规划中，指示物种的选择以及生态廊道位置和宽度的确定是规划的核心，既要预留出充足的动物迁徙及生存空间，又要集约利用土地，并考虑未来发展需求（图3）。

large habitat patches whose sizes range from dozens square kilometers to hundreds; all the patches should be connected with the existing or planned national parks, integrating biological protection with public recreational opportunities such as ecological education and tourism activities.

By May 2018, there had been 11,800 designated nature conservation areas (including 474 reserves) in China, accounting for 18% of the total area of the national territory[20]. However, many of them are cut off by the growing transportation networks and urbanized constructions. In addition, the improper planning of nature conservation areas has resulted in a poor protection coverage of animal species and an increasing threat to the survival of wild animals[21][22]. More efforts are expected to improve the management of nature conservation areas and the construction of ecological corridors to mitigate the fragmentation and link up smaller habitats through planning approaches.

Mountain and forest corridors, riparian corridors, and the ecological corridors between rivers and mountains act as migration paths for animals and birds. Habiting demands of fishes, birds, insects, mammals, and demersal animals, as well as the width requirements of corridors, should be taken into consideration in watershed ecological planning. Biodiversity-sensitive areas and corridors also serve as nationally or regionally significant habitats and gene corridors of key species, whose width should be no less than one kilometer. If a road has to run across such habitats and corridors, eco-bridges or box culverts for animals should be provided. Continuous motorways or bikeways should be avoided from important riparian corridors. The width of riparian corridors is defined by the habiting needs of indicator species that are more sensitive to the environment of habitats — Usually, one or two species of large and small mammals, as well as two or three species of birds (forest birds, migrant and resident waterfowls), are selected as the indicator species; species of amphibians, fishes (especially migratory fishes), and insects can also be selected if necessary. In planting planning, the dynamic evolution of vegetation communities should be reflected by creating sound hydraulic conditions and terrains for plant growth. To sum it up, as the core tasks in ecological watershed planning, the selection of indicator species and the determination of the site and size of ecological corridors need not only to meet animals' migration demands, but also make a smart use of land for future development needs (Fig. 3).





3 结论

笔者在过去十几年的流域生态规划实践中发现，生态规划的落地需要相应的土地资源作为支撑。但中国土地资源有限，特别是流域规划往往面临着巨大的基本农田保护压力，因为河流两侧基本是农业用地的黄金地块。此外，还存在不同的生态要素由不同部门分别进行规划，导致用地及相关保护工作缺乏协同整合的问题。流域生态规划需要在整个流域范围内进行河流网络及滞洪区域规划，将湿地、湖泊等

3 Conclusion

Based on her years of ecological watershed planning practices, the author found that the planning implementation greatly relies on the utilization of land resources. However, the land demand in China is increasingly critical, especially to watershed planning which sees a huge pressure in the maintaining basic farmlands since in China agricultural development is often defined by river systems. Another problem is that land utilization and protection are divorced due to the fact that different ecological factors are planned or managed by different departments independently. Ecological watershed planning should be conducted at watershed scales and envision an overall picture of all the rivers and flooding areas included, while employing wetlands and lakes for stormwater detention and storage, water resources distribution,

3. 江西省抚河流域生态廊道规划。项目团队规划了山脊及沿河廊道，并为大型哺乳动物规划了大型栖息地。

3. The ecological corridor planning of the Fuhe River Basin in Jiangxi Province. The project team planned corridors along the ridges and rivers as well as large habitats for large mammals.

作为滞洪蓄洪、水资源利用、地下水补给、生物栖息地等的载体，将河流两侧及湖泊周边绿地作为洪泛空间及生物廊道，并对农业及城市面源污染进行截留，将一些生物多样性敏感区域及其廊道作为国家及区域级重要物种的栖息地和基因廊道，将这些空间织成跨越各个县、市、省的生态网络，在限定区域内开展生态教育活动，在生态保护的前提下开放部分旅游区域。生态网络也是未来限制城市增长的边界，要分期规划、动态控制，确保核心廊道的连续性。规划师与设计师有能力统筹协调各个专业，使土地和水系空间发挥多重生态效益，实现土地的集约利用并为未来发展预留空间，而实现这一愿景的前提是在国土空间规划中将城市总体规划与流域生态规划相结合。**LAF**

致谢

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groundwater recharge, as well as providing wildlife habitats. Riparian areas and lakefronts should be planned as flooding areas and animals' eco-corridors, where agricultural and urban nonpoint source pollution should be prevented. Areas valuable for biodiversity protection, as well as the eco-corridors included, should be planned as the habitats and gene corridors of key species. All of these areas can be integrated into an ecological network that might cross administrative boundaries of counties, cities, or provinces, where limited ecological educational and tourism activities can be carried out. Such an ecological network also defines the territory of future urban development and should be planned in phases and controlled dynamically so as to ensure the connectivity of key eco-corridors. Planners and designers are expected to strengthen cross-disciplinary collaboration to maximize the ecological benefits of land and water resources and leave room for future development — integrating urban master planning with ecological watershed planning into the territorial spatial planning process offers a path to fulfill the vision. **LAF**

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