时间 2021年8月8日
地点 江西省上饶市婺源县
拍摄 俞孔坚

左图拍摄于江西省上饶市婺源县大鄣山山脚，山间小溪被水泥堤坝所困，两岸湿地消失殆尽，水面上漂浮着各种除草剂和化肥的塑料包装。此时，雨季刚刚过去，来自山林的溪水仅在穿越了不足两千亩的农田后，就遭受到农药和化肥的严重污染，大量水生生物也已绝迹。最终，这条溪水将汇入长江。右图拍摄于渤海湾的海滨沙滩，这里承载着来自陆地的面源污染，导致水体严重富营养化。这片曾经丰饶的海湾，而今已被判定为生态学意义上的“死海”。我们的水生态系统早已病入膏肓！

Date August 8, 2021
Location Wuyuan County, Shangrao City, Jiangxi Province
Photographer Yu Kongjian

The left picture shows the foot of Dazhang Mountain in Wuyuan County of Shangrao City, Jiangxi Province. The watercourse of a stream is cut by concrete dams; the wetlands on both sides of the stream have disappeared; and plastic packages of herbicides and fertilizers are floating on the water surface. Right after the rainy season, the stream sourcing from deep mountains and forests has been severely polluted by pesticides and fertilizers used in the farmland, killing a large number of aquatic organisms. This stream finally flows into the Yangtze River. The right picture shows the beach of Bohai Bay suffering from non-point source pollution from the land, which leads to serious eutrophication. This once vibrant bay is now “lifeless” in the ecological sense. Our aquatic ecosystem is deteriorating fast!

构建和修复一个健康的水生态系统
Building and Restoring a Healthy Aquatic Ecosystem

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摘要

洪涝灾害正越发频繁地造访城市，造成了巨大的生命财产损失，这反映出现代城市缺乏应对不确定的自然灾害的韧性，以及整体水生态系统处于病态的现状。随着全球气候变化的加剧，水生态系统的安全与健康正面临着严峻挑战。笔者强调了从系统层面出发探讨水相关问题的必要性，认为应从生态系统服务的视角来理解、保护和修复水生态系统，并评价其健康状态。只有赋予水充足的空间，从宏观－中观－微观尺度构建水安全格局，才能有效提高水生态系统韧性、修复水生环境与生境，进而重建水与人类和谐共生的关系，滋养健康繁荣的生态文明。

关键词

水生态系统；水生态修复；生态系统服务；洪涝灾害；基于自然的解决方案；可持续性

ABSTRACT

Cities are suffering from more floods than ever, causing huge loss of life and property. The reason is that modern cities often lack resilience to the uncertainty of natural disasters. Aquatic ecosystems on the whole are unhealthy. As global climate change intensifies, aquatic ecosystems are facing more severe challenges. The author explains the necessity to cope with water-related issues holistically, and contends that aquatic ecosystems should be evaluated, protected, and restored based on the understanding of ecosystem services they provide. The water security patterns at macro, medium, and micro levels help improve the resilience of aquatic ecosystems, restore the aquatic and hydrophytic habitats, reconstruct the harmony and symbiosis between water systems and humans, and nourish the health and prosperity of ecological civilization.

KEYWORDS

Aquatic Ecosystem; Water Ecosystem Restoration; Ecosystem Services; Flood Disasters; Nature-Based Solutions; Sustainability

翻译 | 田乐、肖杰
TRANSLATED BY | Tina TIAN, XIAO Jie

刚刚过去的7月，除了持续变异升级的新冠肺炎（COVID-19）疫情威胁着世界各地的人民以外，洪涝肆虐的报道亦成为各国媒体的头版头条。从7月12日到7月底，在德国、比利时、荷兰等欧洲最富裕的地区发生的发洪涝灾害已吞噬228条生命，其中有184人丧生于素有“工程师故乡”之誉的德国，而这也是德国自1962年北海洪水以来最惨烈的一次自然灾害[1]；7月20日，中国郑州的特大暴雨事件中，截至8月2日12时已致292人遇难[2]。这些洪涝灾害几乎都发生在经济发达的国家和地区——这或许就是我们常常将自然灾害与人类文明相提并论的原因。在遭受灾害的城市中，包括地铁、公交在内的交通系统，手机、宽带等通讯系统，以及水电系统等人类文明的象征一度瘫痪，城市脆弱性暴露无遗。此外，在许多城市公园完好无损、许多内部河道也并未出现过大洪水的同时，一些与人民生命安全密切相关的服务设施却面临着巨大风险，如郑州阜外医院恰恰处在城区最低洼地带[3]。

反思之声在业界和外界哄然而起。笔者以为最应反思的是现代城市缺乏应对不确定的自然“灾害”的韧性，这反映了整体水生态系统的病态。对于韧性较高的城市而言，这些“事件”并不足以构成洪涝灾害。殊不知，正是人类引以为豪的钢筋水泥所构筑的、坚不可摧的灰色基础设施（如堤坝和大型水库等复杂的工程设施），将自然过程转变为了“灾害”。其实，与水相关的灾害何止洪涝，工业化、城镇化，以及全球气候变化正使世界范围内（尤其是在中国）的人水关系矛盾日益尖锐，水和以水为主导因子的生态系统的安全和健康问题已经威胁到人类及我们赖以生存的环境的可持续性！

地球上的任何生态系统都离不开水，因此，我们很难脱离地球科学和地理学来探讨水的健康。但水又不得不受到特别关注，人们一开始就试图探讨水的分布、运动和管理，从而发展出了水文学；后来，人们发现水与生物具有密切关系，并构成了相互作用的系统，即水生态系统，因而发展出了生态水文学；接着，发现水和人类也是相互作用的系统，于是又发展出了社会水文学；再后来，干脆将研究与水相关的科学全部统一称为水科学。然而，上述这些关于水的学科似乎仍无法涵盖笔者关心的问题，即探讨系统性的水／完全的水[4]；既是地理学和水文学意义上的水，也是孕育生命的水。她是多尺度的空间存在，从生境和场地，到城市和区域，再到国土和全球；同时，水与大地、城市、乡村、动植物和人类及其活动相互作用，构成了水生态系统。她既表现为水与其他景观元素或水生态系统与其他生态系统之间的空间格局与过程的关系，也表现为水生态系统的内部结构和功能的关系，其中包括物质流、物种流、能流和信息流。在任何尺度上，人的因素都是不可或缺的，甚至是占主导地位的。

因此，我们需要从生态系统服务的视角来理解、保护和修复水生态系统／水系统，并评价其健康状态，具体包括：支持服务，即提供栖息地，支持生物传播、繁衍和迁徙等生命承载能力；供给服务，即提供水及水产；调节服务，即应对洪涝和干旱等环境变化的生态韧性；以及文化服务，即提供审美启智、文化认同、归属感和休憩等服务。一个病态的水生态系统，不但不能给予人类良好的生态系统服务，反而会危害人类的健康甚或生存。

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而要维护健康的水生态系统，最根本的措施是给水以自由。只要考察一下历史上最严重的洪水灾害，就会发现最威胁生命财产安全的往往都是决堤。典型例子包括：1962年德国的北海洪水事件即是洪水冲垮堤坝所致；1975年8月8日的河南驻马店特大暴雨，堪称世界最惨洪灾，死亡人数以万计，也是由板桥水库、石漫滩水库等一系列水库连环决堤造成的[5]；中国历史上有记载的、造成巨大生命财产损失的黄河洪灾，也都是决堤带来的；即使是1960年建成的意大利的瓦依昂大坝，算得上是当时世界上最坚固、最高的大坝，也在1963年10月9日的深夜，遭遇了严重的岸坡下滑，几乎掀翻了整个水库，近两千人在睡梦中丧命。所谓的“压迫越深重，反抗也将越猛烈”，不仅适用于人类社会的关系，也适用于人与水的关系。要与水谋安全、谋和谐，首要之策便是适应和规避水的不可抗力——道理很简单，水需要足够的空间。虽然人类文明在一定程度上意味着从必然王国走向自由王国，即人类通过对自然的控制而获得自身的自由；相反，若人类剥夺了自然的自由，也必将遭受自然的反抗。这并非在否定人类文明的成果，而是强调在应对不确定的自然过程时，任何对抗自然力的灰色人工技术和设施，无论它们多么坚固和复杂，最终都会因其韧性的局限而加剧自然的破坏性。

那么，水到底需要多大的自由空间？以中国为例，在宏观的国土尺度上，早在2006年，北京大学研究团队便探讨了国土尺度水源涵养安全格局，并发现只要保护和恢复占国土面积43.6%的山脉体系，国土尺度上的水源涵养便会达到良好状态，对于一个山地和丘陵占了近70%的国家来说，这似乎是可以实现的。而通过洪水调蓄安全格局的分析发现，在季风气候的条件下，每年的洪水淹没区域大约在国土面积的0.8%~2.2%之间。[6]因此，一个听起来浪漫的假设是：将这些洪涝频发的土地归还于水，困扰中国几千年的人水矛盾便会得到彻底解决。

然而，这些适合作为生态蓄洪区的国土，也正是河漫滩上最为肥沃的土地，它们占全国耕地面积的6%~15%左右[7]。归还河漫滩在几十年前都是不可接受的，因为在当时，保护一亩三分地，就是保护一家人的生存机会。但在今天，这不再是个奢侈的假设。仅从经济角度来讲，如今的中国，农业产值仅占全国GDP的8%，事实上，大量土地撂荒已成为广大农村的普遍现象。间隙性淹没可以滋润河漫滩与洪泛区因被用作农田而日渐贫瘠的土地，并修复其所在的水生态系统。与动辄以亿元计的灰色防洪工程投资相比，哪一个更具经济性已不辩自明。更重要的是，通过释放水域空间，数千年来被破坏的国土水生态系统将会逐渐修复。有人会问：淹没区的数千万人口如何安置？宏观层面的城镇化发展机遇、中观层面的生态优先的新城镇选址和规划、微观层面的高台避洪策略，以及与水共生的生态智慧和健全的洪涝灾害防控体系的建立，都将为此战略的可行性做出贡献。然而，当前泛滥全球的、粗暴的大型水工设施，包括拦河大坝、防洪高堤、大型水库、长距离跨流域调水、侵占水域，以及低洼地的造城行为等，正在为保障国土和区域的水生态系统健康带来巨大压力。

在中观的城镇和乡村尺度上，一个健康的水生态系统体现在如何使水在建成区内拥有足够的自由空间，以及如何寻找合适的地方就地滞蓄，自然积存、自然净化、自然渗透并补充地下水，以保持地下水平衡，并保证湿地与溪流拥有足够的水来滋养与其共生的生物群落。鉴于缺水乃是中国、也是世界范围的人水矛盾的关键，建设并维护像海绵一样具备韧性、能适应极端暴雨事件的水生态基础设施，是人工干预下的城乡水生态系统达到健康状态的标志——而这也正是海绵城市的出发点。关于这方面的智慧，世界上的许多古老文明都为我们留下了丰厚的遗产，包括在高山上建造梯田以涵养水源，在平原上挖掘坑塘以调节旱涝，在河漫滩和三角洲营造桑基鱼塘以利栖居和生产，在沼泽水域上堆土成垛、营建水上田园，在城市和乡村聚落中修建水塘沟渎，以适旱涝之变。从黄泛平原两千多年的水城关系来看，城市中足够的“海绵体”（如水塘湿地）是保障城市韧性的水生态基础设施[8][9]。当前，为了治理城市洪涝灾害而利用灰色管道构建的集中式排水系统和钢筋水泥式的深隧工程等设施会导致城市水生态系统问题的进一步恶化——这些都将在未来被证明是无效的，甚至是饮鸩止渴的。对这样的灰色基础设施的过度依赖，无疑会导致人民的生命财产安全随全球气候的变化和不确定性的增加而面临巨大风险。

在微观的水体、湿地等水生生境尺度上，一个健康的水生态系统体现在生物与水之间的良好生态关系上。生物离不开水，同样没有生物的水也是死水！植物的吸收和蒸腾作用让水分得到循环；植物的生长和死亡能净化和丰富水体中的养分；以水为媒，物种得以繁衍和迁徙扩散。湿地之群落、水岸之形态，溪流之水竭、深潭浅滩之变化等，都是一个健康的水生态系统中举足轻重的元素。

基于上述认识，维护安全与健康的自然和人类水生态系统，离不开三大关键策略：1）保障水源涵养和洪水调蓄安全格局，给水自由的空间，通过水安全格局的规划，划定人—水交集边界，奠定人水和谐共生的空间格局；2）提高水生态系统韧性，即构建海绵国土——包括海绵城市、海绵田园等——来实现城水相融，而核心就是源头就地滞蓄、过

程减速消能、末端弹性适应；3）修复水生环境与生境，去工业化、变灰为绿、削减人工合成化学物质的危害；重建水与田园、人与其他生物的和谐共生关系，使水生态系统蓝绿交织、清新明亮。

这三大策略都是基于自然的途径，但这并不是提倡回到传统农业时代或渔猎时代，而是希望在批判吸收以往文明成果的基础上，创造新的、生态的文明，唯有如此，水生态系统与国土生态系统才能健康、美丽，从而滋养出一个健康、繁荣的社会，即所谓“生态兴，则文明兴”。**LAF**

In addition to the COVID-19 virus variants that keep threatening people all over the world, raging floods made headlines across the globe in July. From July 12 to the end of the month, floods in most affluent European countries, such as Germany, Belgium, and the Netherlands, killed 228 lives—Germany, “the hometown of engineers,” suffered from the worst natural disaster in the country since the North Sea Flood of 1962, causing 184 deaths[1]. On July 20, 292 people died (by noon on August 2) in a cruel storm in Zhengzhou, China[2]. These floods mostly took place in developed countries or regions—Maybe this implies the relation between natural disasters and human civilization. In the disaster-stricken cities, symbols of civilization—transportation systems, communication systems, as well as water-power systems—all paralyzed overnight. While many urban parks were little damaged and no severe floods were seen in the rivers inside the parks, the city’s daily service facilities have to faced huge risks. For instance, Zhengzhou Fuwai Hospital is located in the lowest part of the city[3].

Wide debates on the urban infrastructure construction arose since the 7·20 Zhengzhou Storm. In the eyes of the author, the most sticking problem is that modern cities often lack resilience to the uncertainty of natural disasters. In other words, on the whole, our aquatic ecosystems are sick. For cities with greater resilience, such storms would not lead to so much loss. However, it is the indestructible gray infrastructures—including the complex engineering facilities such as dams and large reservoirs—built with concrete and steel that turn these natural processes into “disasters.” In fact, besides floods, water disasters are increasingly frequent along with industrialization, urbanization, and global climate change, exacerbating the conflicts between human and water around the world, especially in China. The safety and health of the water and aquatic ecosystems has profound impacts on the sustainability of mankind and our living environment!

Water is essential to all ecosystems on the earth. The study of water health is difficult in isolation from Earth Sciences and Geography, but it still requires special attention. We exploring the distribution, mobility, and management of water, Hydrology emerged; We discovering the affecting patterns of water on organisms and the causality on aquatic ecosystem, Ecohydrology was proposed; We studying the coupled human-water system, Sociohydrology came into being. Later, disciplines that study water are viewed as Water Science. However, research in these disciplines still have not explored the water as a holistic system oriented subject[4], which is not only in the geographic and hydrologic sense, but also about the essence of life; which exists across spatial scales: habitats and sites, cities and regions, countries and the globe. Water interacts with land, cities, villages, animals, plants, humans and their activities, as the aquatic ecosystem, which covers not only the relationship of spatial patterns and processes between water and other landscape elements or water ecosystem and other ecosystems, but also the structures and functions within the ecosystem, including the interactions between the flows of materials, species, energy, and information. Human is indispensable, or even crucial to aquatic ecosystems at all scales.

Therefore, we need to evaluate, protect, and restore aquatic ecosystems/water systems based on the understanding of ecosystem services. The aquatic ecosystems provide supporting services, i.e. providing habitats, and supporting species spread, reproduction, and migration; provision services, i.e. providing water and aquatic products; regulating services, i.e. maintaining ecological resilience in response to environmental

changes such as floods and droughts; and cultural services, i.e. fostering aesthetic tastes, cultural identity, sense of belonging, and offering recreational spaces. Unhealthy aquatic ecosystem cannot provide sound ecosystem services for humans, or worse, endanger human health or survival.

Maintaining the natural flow is critical to the health of aquatic ecosystem. In history, most damaging floods were caused by dyke bursting. Examples include the North Sea Flood in Germany in 1962 and the heavy flood in Zhumadian, China on August 8, 1975. The latter was one of the most disastrous in history, leading to tens of thousands of deaths, and also caused by serial bursting of the Banqiao Reservoir, the Shimantan Reservoir, and others[5]. Recorded floods that took place along the Yellow River and caused huge loss of life and property also resulted from dyke bursting. The Vyion Dam in Italy built in 1960 was seen as the solidest and highest dam in the world of the time. On the evening of October 9, 1963, a sudden landslide shattered the entire reservoir, and nearly two thousand people died overnight—As the saying goes, "the harder the oppression, the more violent the resistance will be." This is also true to the relationship between man and water. To harmonize with water, it is necessary to allow sufficient space for the natural flow. Although human beings are gaining greater freedom through the control over nature, but are more terribly retaliated by the nature at the same time. I'm not denying the achievements in human history, but pointing out that gray artificial techniques and facilities which go against nature would exacerbate the destructive force of nature due to the inadequate resilience.

Then, how large the space do we need for the natural flow of water? Take China as an example. In 2006, the research team from Peking University explored the security pattern of water conservation at the national scale, and found that as long as protecting and restoring the mountains, accounting for 43.6% of the total territory, the water conservation at the national scale will be greatly improved. This goal is possible for China, a country where mountains and hills account for nearly 70% of its territory. An analysis of the security pattern of flood regulation and storage showed that, under the monsoon climate, the annually flooded area ranges from 0.8% to 2.2% of the territory.[6] Therefore, a romantic hypothesis would be that, after experiencing the unprecedented urbanization in history, the flood-prone land areas would be reserved for the natural flow. Then the human-water conflicts that have troubled China for thousands of years will be addressed radically.

However, this flood storage area, accounting for 0.8% to 2.2% of China's territory[6], is the most fertile land on the floodplain (taking up a proportion of 6% to 15% of the arable land)[7]. It was unrealistic to turn arable land into flood storage area decades ago, when agriculture product contributed to most households' income. But today it is no longer a fantasy: Agriculture product now accounts for only 8% of China's GDP, and a considerable amount of arable land is left uncultivated in rural areas. Being impoverished due to excessive reclamation, the farmlands of floodplains and the whole farmland ecosystem could be restored by occasional inundation. Compared with the enormous investment in gray infrastructure projects for flood control, water system restoration is much more economical. More importantly, the damaged territorial aquatic ecosystem would be restored step by step as the increase of water space. The tens of millions of residents from the inundated areas can be well resettled through smart urbanization at the macro level, ecology-prioritized site selection and planning strategies for new towns at the medium level, and flood risk control measures such as building high platform at the micro level, together with the ecological wisdom of co-living with water and the building of a sound flood security system. However, large-scale hydraulic projects like barrages, levees and reservoirs, long-distance water diversion infrastructures across watersheds, waters invasions, and construction activities in low-lying areas, are endangering aquatic ecosystems.

A healthy aquatic ecosystem in cities, towns, or villages requires sufficient spaces for flood retention and storage in the built-up areas. Natural water storage, purification, and infiltration, as well as recharging of groundwater, ensures water circulation and stable water supply for wetlands and streams to nourish

aquatic species. As water shortage is critical to China and other countries across the world, it necessitates the construction of resilient water ecological infrastructures to adapt to extreme rainstorms like "sponges," thus guarantee the health of urban and rural aquatic ecosystems—This is also the goal of Sponge City construction. Many ancient civilizations left behind vast legacies in smart water management, such as developing terrace fields to conserve water, building ponds to regulate droughts and floods, creating mulberry-fish ponds in floodplains and deltas to foster local aquiculture, piling up soil on marshes to build water gardens, and digging ponds and ditches in urban and rural settlements. The history of the water-city co-existence in the Yellow River Basin tells that creating sufficient "sponges" (such as ponds and wetlands), as important water ecological infrastructures, can ensure urban resilience[8][9]. The centralized drainage systems built with gray pipelines and deep tunnels made of concrete and steel are introduced to control urban flooding. But they often prove to be ineffective and unsustainable in urban water system management. Over-dependence on such infrastructures will put people's lives and property at huge risks due to the global climate changes and uncertainties.

At the micro-scale of hydrophytic habitats such as water bodies and wetlands, a healthy aquatic ecosystem sees dynamic interactions between organisms and water. Organisms and water are interdependent. The absorption and transpiration of plants facilitate water circulation. The growth and decay of plants clean and enrich the nutrients in the water body. Species can multiply and migrate via water. To build a healthy aquatic ecosystem, we need to pay attention to the communities in wetlands, forms of waterfronts, courses of streams, and changes in beaches.

There are three strategies on how to build safe and healthy aquatic ecosystems: 1) Ensure the security pattern of water conservation and flood regulation, allow for water's natural flow, and define the interface between human and water through water security pattern planning to rebuild human–water harmony; 2) Enhance the resilience of aquatic ecosystems by building "Sponge Land" —including Sponge City and Sponge Countryside, increasing on-site flood storage, slowing down water flow processes, and improving the resilience of tail-end sponges; and 3) Restore aquatic and hydrophytic habitats, promote deindustrialization, minimize the use of synthetic chemicals, rebuild the harmony between water and fields, human and the nature, and enhance the integration of blue–green spaces.

These strategies are all nature-based solutions. Instead of calling for reintroducing of the lifestyles or production modes of the agricultural age or the fishing-hunting age, the author encourages building a new ecological civilization upon legacies. Only in this way could we have healthy and beautiful water systems and territorial ecosystems, for a greater societal prosperity. **LAF**

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