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水灾害生态化防治理论模式与关键技术路径

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摘要:基于极端水循环特征,结合富自然-功能协调流域、灰绿基础设施协同等前沿理论,阐释水灾害生态化防治内涵与理论基础;提出灰绿协同的水灾害防治新范式,即集水文畸变三维诊断、径流系数时空重塑、产水与耗用水双控等技术于一体的技术体系;面向当前水旱灾害防御体系转型需求,提出了分区分类实施、智慧化管理、体制机制创新等切实可行的实施路径。研究成果旨在为推进水灾害防治从工程主导的"蓄""导"模式向生态优先的"适应模式"转型提供理论支撑和技术路径。

关键词:水旱灾害;生态化防治;水文调蓄;灰绿工程;富自然-功能协调流域

Theoretical modes and key technological pathways for ecological prevention and control of water disaster//Yan Denghua[1,2], Wang Hao[1], Bi Wuxia[1,2], Zhang Xin[1,2], Qin Tianling[1,2], Weng Baisha[1,2], Li Wei[1,2](1. *State Key Laboratory of Water Cycle and Water Security*, *China Institute of Water Resources and Hydropower Research*; 2. *Technology Innovation Center for Flood and Drought Prevention and Disaster Reduction*, *Ministry of Water Resources*)

Abstract: Based on the characteristics of extreme water cycle, the connotation and theoretical basis of ecological prevention and control of water disasters were explained by combining frontier theories, such as Nature Enriched and Attributes Coordinated Watershed and gray-green infrastructure coordination. A new paradigm for water disaster prevention through gray-green infrastructure—a technical system integrating Three-Dimensional Diagnosis of Hydrological Distortion, Spatiotemporal Remapping of Runoff Coefficient, and Dual Control of Water Yield and Consumptive Use were proposed. Addressing the current need for transforming water disaster defense systems, it outlines practical implementation pathways including zoned and categorized implementation, intelligent management, and institutional mechanism innovation. These findings aim to provide the theoretical underpinnings and technical pathways to advance a critical shift in water disaster prevention, involving moving from an engineering-led "storage" and "dredge" mode to an ecology-first "adaptation mode".

Key words: flood and drought disaster; ecological prevention and control; water regulation; grey-green infrastructures; Nature Enriched and Attributes Coordinated Watershed

全球气候系统正经历以变暖为主要特征的深刻变革,水文循环呈现显著的极端化趋势[1-2]。我国作为世界上水旱灾害最为严重的国家之一,近年来极端水文事件频发,2021 年郑州特大暴雨最大降水量达 201. 9 mm/h,突破我国陆地小时降水量极值[3-4];2020 年长江流域性洪水多个水文站点流量创 1954 年以来新高[5]。与此同时,生态系统退化与水文畸变形成恶性循环。据《2022 年中国水土保持公报》报道,我国水土流失面积达 269. 27 万 km^2,大量湿地湖泊萎缩,这些生态系统的退化显著削弱了流域的自然防御能力[6]。生态系统退化导致调蓄能力下降,进而加剧灾害风险[7];而灾害发生又进一步破坏生态系统,形成正反馈效应[8-9]。我国在水旱灾害防治方面取得了举世瞩目的成就,建成了较为完善的水旱灾害防御体系,有效保障了经济社会发展和人民生命财产安全。然而,随着极端天气事件的增多增强,新建大型调蓄工程的条件有限,传统以堤防、水库、蓄滞洪区等灰色基础设施为主体的防御体系正面临新的挑战,具体表现为气候变化引发的极端水文事件冲击、生态功能缺失导致的系统性风险、城市化与空间开发的挤压、管理与适配性的滞后、灾害类型的复合型挑战等。

以灰色工程措施为主的防御体系主要存在以下几个方面问题:①生态系统服务功能退化严重。大

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