Proceedings of the 10th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/2026.38305

International Experience in Water Network Construction from a River Basin Management Perspective and Its Implications for China

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Abstract. Against a backdrop of global climate change and growing regional tensions between water supply and demand, both high-quality development and high-level protection require better allocation of basin water resources and stronger water security. Cross-regional water-network construction has become an important way to improve coordinated basin allocation. As the basic unit for integrated water-resources management, the basin needs water projects to be deeply integrated with its management system. This is a key condition for sustainable water use. This article reviews four international experiences: cross-regional collaborative governance, full-chain legal control, market-based operation of water projects, and integrated ecological restoration. It then examines China's current basin-planning system, backbone projects, tiered coordination, and smart operation and maintenance. Four practical problems are identified: barriers to integrated basin governance, weaknesses in the legal control system, incomplete market-based allocation mechanisms, and slow ecological upgrading of water projects. Drawing on international practice, the article proposes pathways in four areas: basin governance, water-network layout, market-based operation, and basin ecological security. Specific measures include improving basin-specific laws, building cross-regional coordination mechanisms, coordinating water projects at different levels, improving water-rights and tiered-pricing systems, creating a basin-wide smart dispatch platform, upgrading water projects ecologically, and building climate-adaptive water networks. These findings add to the theory of national water-network construction from a basin-management perspective. They also offer a reference for integrated water-network construction and modern basin water governance in China.

Keywords: national water network,river basin management, international experience, water-resources allocation, implications

1. Introduction

With global climate change and rapid economic and social development, water-ecosystem degradation, frequent water disasters, and cross-regional water conflicts have become increasingly serious. Traditional water-resources management is gradually falling short of current needs. Many countries have therefore promoted water-network construction. They have used inter-basin transfers,

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DOI: 10.54254/2754-1169/2026.38305

connected water systems, and coordinated allocation to improve efficiency and strengthen regional water supply and water security. A national water network is an integrated water-conservancy system. It is based on natural rivers and lakes, and combines water-transfer and drainage projects, storage hubs, and smart regulation. Its main goals are to improve water allocation, reduce flood and disaster risks, and protect water ecosystems [1]. The river basin is the basic unit of modern water management. If water-network construction is not properly integrated into basin management, resource allocation may become unbalanced and ecological protection may suffer. Sustainable water use and modern water governance may then be affected. Against this background, an important scientific question is how to better integrate national water-network construction into basin management so that project construction, resource allocation, ecological protection, and security work together.

Existing research has mainly developed in the following areas.

First, global water-network construction has produced several useful experiences. (a) Artificial water infrastructure can be built on a natural water-system base to create a combined land–water network. Regional natural systems provide the foundation, while engineered projects provide the framework [2]. (b) Planning can respond to local conditions by accounting for regional differences in water supply, demand, and development [3]. (c) Digital technology can be embedded throughout water-network management. This creates an integrated system linking physical projects, information sensing, and basin management [4]. (d) Ecological restoration can be included throughout the construction process, allowing water use and ecological protection to move forward together [5]. After years of development, its water network has moved from scattered individual projects toward system-wide planning and network building [6]. Three-dimensional and regional modern water networks have strengthened system resilience and regional water-carrying capacity. They can reduce water shortages and improve basin environments [7]. At the same time, water networks have become more closely connected with regional economic development, supporting land-space optimization and more balanced regional growth [8].

First, water resources do not always fit well with economic and ecological factors in space. The ecological mismatch is especially serious, which limits coordinated basin development [9]. Second, water-network development is uneven. Third, basin regulation and management are incomplete. The Yellow River Basin, for example, still faces weak regulation and uneven allocation. Barriers between rivers and lakes have also contributed to ecosystem decline and weakened ecological integrity [10, 11]. Fourth, policy simulation and system research remain limited. It is difficult to describe the changing links between water networks and economic and social systems with enough precision. This weakens the scientific basis of basin decisions.

Planning should start from the whole basin and use a systems approach to build a nationwide "one network." Cross-basin and cross-regional allocation should be improved. On the technical side, hydrological and policy models should be linked, and multidimensional allocation models should be developed. For ecological governance, ecological water networks and restored river–lake biological corridors can reconnect water systems and repair basin ecosystems.

Reviews of water-network experience from a basin-management perspective are not yet systematic enough. Few studies examine China's water-network problems specifically through this lens. Recommendations also tend to focus on technology and engineering, while long-term, basin-wide coordination is less developed. This article therefore reviews typical international experiences, analyzes the main problems facing China's national water network, and considers how water-network construction can better fit within basin management. The study uses literature review, case analysis, comparative research, and inductive and deductive reasoning. It compares typical domestic

DOI: 10.54254/2754-1169/2026.38305

and international cases, summarizes mature international practices and their conditions of application, and then offers suggestions suited to China.

2. Experience with water-network construction from a basin-management perspective

2.1. International experience in the management of typical basin water networks

2.1.1. Cross-Regional collaborative governance

To address conflicts between upstream and downstream water users in large transboundary or multi-administrative basins, and the difficulty of coordinating water allocation across separate jurisdictions, many countries have developed mature collaborative models [12].

Many transboundary or large basins have established unified management bodies. These bodies are responsible for basin planning, water dispatch, and water-project management. They manage sources, irrigation districts, and groundwater as one system.

Basin collaboration is usually supported by a common agreement. The agreement sets total withdrawals, groundwater limits, and ecological release flows under different hydrological conditions. It also sets priorities among industrial, domestic, and ecological uses [13].

Finally, a sound hydrological monitoring system is essential. Overseas basins combine weather stations, river cross-sections, groundwater wells, and irrigation-district meters in one monitoring network. They share data on rainfall, runoff, groundwater levels, withdrawals, and water quality.

2.1.2. Full-chain legal control

Mature basins in Europe, the United States, and Australia have built legal systems that cover the whole process from water sources and withdrawals to wastewater discharge.

Many countries have enacted unified basin water laws. These laws clarify joint regulation of surface water and groundwater, and define responsibilities for project construction, operation, and water allocation. Countries commonly use water quotas and withdrawal permits. Agricultural, industrial, domestic, and ecological uses are managed separately. Standards vary with crop type and regional development, while total withdrawals are controlled strictly. When use exceeds a quota, supply limits and tiered prices encourage conservation. Water-saving irrigation is also promoted for high-water-use crops. This helps prevent agriculture from taking water needed by ecosystems. Water administration and oversight are also essential. Agencies regularly inspect channels, groundwater extraction, illegal withdrawals, and pollution from agricultural return flows. Total use, irrigation efficiency, and ecological flows are included in enforcement, helping protect projects and the basin's allocation order.

2.1.3. Coordinated engineering and market-based operation

Many overseas basins combine water-project layout with market mechanisms to improve allocation efficiency. First, many countries use a tiered project system. Reservoirs in upper reaches store runoff. Foothill aquifers provide underground storage. Canal networks in the plains deliver water. Together they create a system of reservoirs, aquifers, and canals. Water-rights trading is also widely used. After total withdrawals are strictly controlled, users that save water may trade surplus rights. Water can then move toward higher-efficiency uses. Differentiated tiered prices are another important conservation tool. Countries set different prices for agricultural, industrial, and domestic

DOI: 10.54254/2754-1169/2026.38305

water. They charge more for use above quotas and offer discounts to users that save water. Revenue from water charges can also support network operation and maintenance.

2.1.4. Integrated project and ecological restoration

Water construction and river–lake restoration are advanced together.

Many countries have ecologically upgraded old dams, gates, and conveyance canals. These upgrades restore river–lake connectivity and reduce the effect of projects on natural water cycles. Adjusting dam releases and adding permeable sections to canals can improve surface-water and groundwater exchange and strengthen basin ecosystems. Overseas basins also commonly include ecological flows in their management systems. They set minimum release standards for wet, normal, and dry years. Water for rivers, oases, and desert vegetation is given priority. This helps prevent channel drying, vegetation loss, and land desertification caused by excessive withdrawal. Flood-control projects, water networks, and wetland restoration are also coordinated. Ecological buffer zones and constructed wetlands improve water retention and water quality. During flood seasons, flood control is combined with ecological replenishment. Floodwater can be used to recharge groundwater and restore wetlands and vegetation.

2.2. Current water-network construction and institutional foundations under China's basin-management framework

2.2.1. A more complete system of basin-wide planning

China has established a basin water-resources management system centered on the strictest water-resources management regime. It has also developed a relatively complete policy framework that can respond to different hydrological conditions. The current system uses three "red lines" to control total withdrawals, water-use efficiency, and pollutant loads in water bodies. This is broadly consistent with the international emphasis on rule-based basin management [14]. After years of planning and institutional improvement, China has gradually built a water-network management framework suited to its land-space pattern and basin-management needs. A series of laws, plans, and policy documents has set implementation rules for planning, project construction, coordination, and smart operation and maintenance. These documents support nationwide integration of water networks (Table 1).

Table 1. Institutions related to China's water-network construction

Document	Year	Issuing body	Core institutional content
Flood Control Law of the People's Republic of China	2016 revision	Standing Committee of the National People's Congress	Establishes unified basin flood-control planning, dispatch, and joint prevention and control; requires water-system connectivity and storage projects to be integrated with basin flood-control systems.
Water Law of the People's Republic of China (revised)	2016	Standing Committee of the National People's Congress	Establishes a water-resources management system combining basin management with administrative-region management; sets rules for unified allocation, river and lake protection, water conservation, and inter-basin transfers.

DOI: 10.54254/2754-1169/2026.38305

Table 1. (continued)

Outline for Ecological Protection and High-Quality Development in the Yellow River Basin [15]	2021	Central Committee of the Communist Party of China and State Council	Responds to water scarcity and weak regulation in the Yellow River Basin by calling for a backbone water-network system and coordinated management of trunk and tributary rivers, water allocation, and ecological restoration.
Guiding Opinions on Basin Water-Ecology Compensation Mechanisms	2021	National Development and Reform Commission and Ministry of Water Resources	Establishes cross-basin and cross-regional compensation for water-ecology protection, including cost sharing, compensation for lost development opportunities, and collaborative governance.
14th Five-Year Plan for Ensuring Water Security	2021	State Council	Calls for a modern water-network system, river connectivity, smart water management, stronger binding constraints on water use, and intensive and precise water allocation.
Outline for National Water Network Construction	2023	Central Committee of the Communist Party of China and State Council	Defines the national water network as a system based on natural rivers and lakes, using water-transfer and drainage projects as channels, storage projects as nodes, and smart regulation as its core. It coordinates allocation, flood control, and ecological protection through a nationwide "one network" approach.

2.2.2. Backbone projects in basin water networks

China has coordinated the construction of major inter-basin transfer projects such as the South-to-North Water Diversion Project. Local governments have also improved small and medium-sized reservoirs, irrigation canals, urban and rural supply networks, and groundwater-recharge projects. A comprehensive storage system led by large projects and supported by smaller facilities is gradually taking shape. In recent years, regions have continued to modernize irrigation districts, build efficient irrigation, jointly operate reservoir groups, and coordinate surface water and groundwater. These efforts have improved storage and supply security, optimized allocation across time and space, and raised national efficiency and water security [16].

2.2.3. A tiered collaborative management system

China uses a three-level system involving basin institutions, local water authorities, and grassroots water-user organizations. The seven major basin institutions coordinate basin-wide allocation and cross-regional dispatch. City and county water authorities operate reservoirs and canals in their jurisdictions. Village and township water-user organizations maintain field irrigation facilities. Total-withdrawal controls, quota management, water-rights transfers, and tiered prices have been introduced. Cross-regional ecological compensation in the Yellow and Yangtze river basins helps address upstream–downstream conflicts. The river-chief system has also been implemented nationwide. Cross-provincial and cross-city joint meetings have created a pattern of shared governance led by government, implemented locally, and supported by public participation.

2.2.4. Smart operation and maintenance of basin water networks

China is coordinating the digital infrastructure for a national water network. Major basins and provinces are installing monitoring hardware. Automatic sensors for water level, flow, quality, and

DOI: 10.54254/2754-1169/2026.38305

rainfall are being placed at reservoirs, rivers, irrigation districts, and storage hubs. Satellite remote sensing, drone inspections, video monitoring, and the Internet of Things are being combined to connect real-time collection, transmission, and cross-regional sharing of hydrological information.

Digital twin basins, hydrological forecasting, and big-data analysis are gradually improving smart dispatch, flood and drought defense, and project operation. Key basins are also developing unified smart-dispatch platforms. These platforms combine rainfall, water quantity, water quality, withdrawals, discharges, and project-operation data. They strengthen data sharing and coordination among agencies, support early warnings and optimized allocation, and improve the digital and intelligent level of basin management.

3. Main problems facing water-network construction in China from a basin-management perspective

3.1. Barriers to integrated basin governance

China has long used a multilevel, multi-actor approach to basin management. Basin institutions mainly handle annual allocation and the operation of large reservoirs. Groundwater, field irrigation, and ecological water delivery are handled by local water authorities and grassroots water-user organizations. Conflicts between upstream and downstream users and between regions remain visible.

Different areas also operate separate monitoring systems. Data on weather, water levels, groundwater, and irrigation measurements are managed in different places. A unified sharing platform has not yet been formed. Basin dispatch therefore relies mainly on local monitoring, unlike the integrated monitoring and collaborative management seen overseas. Existing allocation plans are largely based on average inflows over many years and do not sufficiently reflect wet, normal, and dry years.

In addition, runoff areas in the mountains, groundwater-storage areas at the foothills, and ecological areas downstream are managed by different actors. A unified coordination mechanism is lacking. Joint surface-water and groundwater dispatch is weak, and groundwater has remained overexploited in many places. Backbone projects and field canals are maintained by different actors. Leakage and unauthorized withdrawals are difficult to address quickly. This affects basin-wide allocation efficiency and ecological protection.

3.2. Weaknesses in the legal control of basin water resources

China has enacted basic water laws, including the Water Law of the People's Republic of China, and has established the strictest water-resources management system and its three red lines. However, existing laws are mostly general. Special rules for joint surface-water and groundwater dispatch and ecological protection in dry inland basins are still incomplete. They do not fully fit unusual hydrological conditions.

Some local systems lack clear rules for snowmelt, groundwater development, and ecological replenishment. Groundwater extraction is managed mainly through administrative measures, so legal constraints are limited. Because regions are managed separately, standards for withdrawal permits and water quotas are inconsistent. Ecological water is easily squeezed out by irrigation. Cross-regional groundwater overexploitation, illegal withdrawals, and pollution from agricultural return flows also lack unified oversight. Supervision still focuses on total withdrawals, with less attention to ecological flows and groundwater storage. Supporting accountability mechanisms need

DOI: 10.54254/2754-1169/2026.38305

improvement. Overall, compared with full-chain legal management overseas, China still needs stronger basin-specific legislation, joint surface-water and groundwater management, ecological-flow guarantees, and cross-regional enforcement.

3.3. Shortcomings in project operation and market allocation

China's basin water allocation is still led mainly by administrative management. Water-rights trading and differentiated prices are still being tested, and a unified system covering the whole basin has not yet formed.

Some regions have piloted agricultural water-rights transfers, but initial rights for different types of use are not clearly defined. Ecological water does not yet have separately allocated rights. Industrial and urban users have limited access to trading. A unified trading platform has not been established, so surplus water created through conservation is difficult to transfer efficiently. The market therefore plays only a limited role.

Tiered prices also cover a limited area. Most irrigation districts still use a uniform price. The constraint on use above quotas is weak, and incentives for conservation are limited. Some conveyance canals are aging, while anti-seepage upgrades lag behind, leading to high losses. Operation and maintenance rely mainly on public finance. There are few market-based funding channels, so efficient irrigation upgrades and groundwater recharge lack adequate financial support. Measurement coverage in irrigation districts is also low. Field withdrawals and water-use statistics remain incomplete. Without good data, water-rights trading and tiered pricing are difficult to implement. Dispatch is still based mainly on annual administrative plans, with little room for dynamic adjustment to different demands. Allocation among agricultural, industrial, domestic, and ecological uses can be improved.

3.4. Slow ecological upgrading of basin water projects

China has promoted ecological water projects in recent years, but some older projects were designed mainly for irrigation and flood control. They paid less attention to basin ecology and natural water cycles.

Some reservoirs, dams, gates, and conveyance canals ensure water supply but also affect natural exchange between surface water and groundwater. Joint storage and regulation remain weak. Plain-area reservoirs lose substantial water through evaporation. Surplus surface water in wet seasons is not easily used to recharge aquifers, and coordinated dispatch of multiple sources needs improvement.

Project dispatch still focuses mainly on irrigation. Ecological replenishment is not reliably guaranteed, and ecological flows lack a stable mechanism. This places pressure on ecosystem services. Upgrades to old canals emphasize seepage control and conveyance, while ecological buffer zones and constructed wetlands are less developed. The treatment of agricultural return flows also needs improvement. Flood-control construction and ecological restoration are not yet well coordinated. Wetlands, tidal flats, vegetation, and soil-conservation facilities in mountain areas have been restored slowly. Compared with overseas approaches that advance construction and restoration together, China still has gaps in ecological upgrading, ecological-flow guarantees, and water-ecosystem restoration.

DOI: 10.54254/2754-1169/2026.38305

4. Implications for China

4.1. Improving the basin governance system

4.1.1. Build a basin-specific legal and regulatory system

China should establish a tiered and category-based legal system that fits the hydrological features of different basins. This would support national water-network construction and unified basin dispatch. First, special legislation for key basins should be accelerated. For water-scarce basins, supporting rules should clarify snowmelt use, joint surface-water and groundwater dispatch, and annual ecological release flows. Ecological water should be included as a legally recognized use. The law should also regulate the occupation of ecological water by irrigation. Second, unified implementation rules for withdrawal permits and water quotas should be refined. Differences between regions should be reduced. Cross-regional groundwater limits and standards for agricultural return-flow pollution should be unified. Water development, conveyance, use, and pollution control should be managed according to law throughout the chain. Third, joint water-law enforcement and assessment should be improved. Groundwater storage and the rate at which ecological flows are guaranteed should be included in routine supervision. Joint inspections and enforcement should be established across provinces. This would correct the current emphasis on total withdrawals and relative neglect of ecological protection. Responsibilities between water-network institutions and local governments should also be clarified, strengthening coordination and providing better institutional support for unified dispatch.

4.1.2. Improve cross-regional coordination and benefit-sharing

A long-term coordination mechanism should be established for China's three-level system of basin institutions, local governments, and grassroots water-user organizations. First, the coordinating role of the seven basin institutions should be strengthened. They should be empowered to plan water networks, allocate water, and dispatch multiple sources jointly. They should coordinate development and protection in mountain runoff areas, foothill groundwater-storage areas, and downstream ecological zones. Joint surface-water and groundwater dispatch should be strengthened to ease overexploitation. Second, regular cross-regional consultation and benefit coordination should be established. Cross-provincial joint meetings should be improved, and basin ecological compensation should be strengthened. Water-allocation plans should vary with hydrological years and balance upstream and downstream supply with ecological needs. Third, basin monitoring should be planned as one system. Dispersed stations should be integrated, and a unified data-sharing platform should be built. Standards for weather, runoff, groundwater, and irrigation measurements should be aligned. Clear responsibilities should also be set for backbone storage projects and field canals. Leakage and illegal withdrawals should be addressed more effectively, improving basin coordination and national allocation capacity.

4.2. Improving the water-project system

4.2.1. Coordinate project layout and balanced allocation

First, project construction should be strengthened. Following the Outline for National Water Network Construction, China should use the Yangtze and Yellow river basins and other backbone basins as a foundation, continue major inter-basin projects such as the South-to-North Water

DOI: 10.54254/2754-1169/2026.38305

Diversion Project, and improve north–south and east–west connectivity. This would narrow regional gaps and increase storage capacity in the north [1]. Project layouts should differ according to water conditions and supply–demand patterns. Water-rich areas should focus on river–lake connectivity and wetland storage. Dry inland basins should strengthen mountain reservoirs and groundwater recharge. Reservoirs, aquifers, and conveyance networks should work as one storage system. Economic development, urban and rural supply, and ecological protection should be considered together. Backbone networks should connect better with small and medium irrigation districts and urban and rural supply systems.

4.2.2. Link old and new projects to improve dispatch

Old gates and canals should be connected with new inter-basin hubs and groundwater-recharge projects. Main and tributary systems should be reconnected, barriers between rivers and lakes should be reduced, and natural connectivity should be restored. Joint operation of reservoir groups should be improved. Large backbone reservoirs and smaller supporting reservoirs should follow coordinated rules. Dispatch should vary across wet, normal, and dry periods. In wet periods, surplus water can recharge groundwater and restore wetlands. This may reduce useless evaporation from plain-area reservoirs and support joint storage of surface water and groundwater. Irrigation modernization should be advanced together with backbone-network construction. Old canals should be upgraded to reduce seepage, field facilities should be improved, and the last link between backbone networks and fields should be completed.

4.3. Reforming water-network operation

4.3.1. Improve water-rights trading and pricing

The water-rights system should be clarified. Initial rights for agricultural, industrial, domestic, and ecological uses should be defined. A unified basin-wide trading platform should be built. Trading channels among agricultural, industrial, and urban users should be opened, and users that save water should be encouraged to transfer surplus water lawfully. Differentiated tiered prices should be improved. Prices should reflect agricultural, industrial, and domestic use. Use above a quota should be charged progressively, while conservation should receive an appropriate discount. Funding sources for construction and operation should be broadened. Revenue from tiered prices can support reservoir and canal maintenance, efficient irrigation upgrades, and groundwater recharge. Measurement and monitoring in irrigation districts should also be strengthened.

4.3.2. Build a basin-wide smart monitoring and dispatch system

The space–air–ground monitoring network should be improved. Automatic devices should be installed at reservoirs, rivers, irrigation districts, and groundwater wells. Remote sensing, drones, and the Internet of Things should be used to combine rainfall, runoff, water quality, withdrawals, and project-operation data. A unified basin data-sharing platform should support sharing among regions and agencies. Digital twin basins should be developed. Hydrological forecasting, water-allocation, and policy-simulation models should be linked to improve analysis of network operation, economic and social development, and ecological change. Cross-basin smart dispatch platforms should be improved. Water, ecology, agriculture, and natural-resources agencies should coordinate

DOI: 10.54254/2754-1169/2026.38305

their work. Real-time warnings, multi-source allocation, and precise project dispatch should then become possible.

4.4. Strengthening water-network ecological security

4.4.1. Promote ecological governance and ecological upgrading

Existing gates and conveyance canals should be upgraded ecologically. Release operations should be improved, permeable canal sections should be added, and natural surface-water and groundwater exchange should be restored. Biological corridors between rivers and lakes should also be repaired. A legally guaranteed ecological-flow system should be established. Minimum release standards should be set for wet, normal, and dry periods. Ecological replenishment should become a routine dispatch task. Water for rivers, oases, and vegetation should be secured, preventing channel drying and desertification. Ecological buffer zones and constructed wetlands should be built alongside water projects. Farmland return-flow purification should be improved. Flood-control, soil-conservation, tidal-flat, and wetland restoration projects should be implemented together. Basin-wide restoration can then follow the water network's connected structure.

4.4.2. Build a climate-adaptive water-security system

Smart monitoring and dispatch should support better medium- and long-term hydrological and climate forecasting. Dispatch plans for different years and seasons should reflect climate patterns. Multilevel storage should be strengthened. Mountain reservoirs, aquifers, and wetlands can form a layered storage system. Floodwater can be used to recharge groundwater and restore wetlands, improving circulation and easing water shortages and ecological decline. Climate adaptation should be included in national and basin water-network plans. Different basins and climate zones need different approaches. Dry northern areas should focus on groundwater storage and water-saving projects. Rainy southern areas should improve connectivity and flood-storage facilities. A dynamic basin water-security assessment should also be established. Plans for dispatch, ecological replenishment, and allocation can then be adjusted as climate conditions change.

5. Conclusion

International experience shows that effective water-network construction depends on integrating basin-wide governance, full-chain legal control, coordinated engineering and market mechanisms, smart monitoring, and ecological restoration. China has established important institutional and engineering foundations, but fragmented governance, incomplete basin-specific rules, limited water-rights and pricing mechanisms, uneven data sharing, and slow ecological upgrading continue to constrain coordinated allocation and ecological security.

Accordingly, national water-network construction should strengthen the coordinating role of basin institutions, improve basin-specific laws and cross-regional benefit sharing, connect backbone and local projects, and support joint operation across wet, normal, and dry periods. A basin-wide smart monitoring and dispatch system, clearer water rights and differentiated pricing, ecological-flow guarantees, ecological upgrading of existing projects, and climate-adaptive multilevel storage can help align water allocation, project operation, ecological restoration, and regional development.

DOI: 10.54254/2754-1169/2026.38305

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