

Research on Ecological Flow Guarantee and Aquatic Ecosystem Restoration in the Lower Reaches of the Fen River

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Abstract: As the second largest tributary of the Yellow River, the downstream section of the Fen River serves as a critical ecological barrier for maintaining the water ecological security of the middle Yellow River and achieving the goal of "clear water flowing into the Yellow River." Over the long term, the downstream Fen River has faced prominent ecological issues such as insufficient ecological flow, excessive water quality fluctuations, habitat degradation, and sharp declines in biodiversity, primarily due to human activities like excessive water resource exploitation, pollution discharge, and artificial river modifications. This study focuses on the section of the Fen River downstream from Linfen to its confluence with the Yellow River, systematically analyzing the current state of regional water resources and aquatic ecosystems, identifying core challenges, exploring ecological flow calculation and assurance technologies, and integrating the development of an appropriate water ecological restoration pathway for the Fen River downstream. Targeted comprehensive management and long-term control strategies are proposed. The research findings can provide theoretical support and practical references for ecological governance in the Fen River Basin, optimized water resource allocation, and long-term restoration of aquatic ecosystems, contributing to the ecological protection and high-quality development of the Yellow River Basin.

Keywords: Downstream of Fen River; Ecological Flow; Water Resource Scheduling; Water Environment Restoration; Watershed Management

1. Introduction

Ecological protection and high-quality development in the Yellow River Basin are major national strategies, and ecological

management of tributaries is the core link of comprehensive management of the Yellow River Basin. The Fen River is one of the most important tributaries of the Yellow River Basin, running through the core area of southern Shanxi. The downstream section receives water from the upstream, connecting the two major cities of Linfen and Yuncheng, and ultimately flowing into the Yellow River. It is not only the core carrier of regional water resource utilization, but also an important channel for the input of Yellow River sediment and pollutants. With the rapid development of regional urbanization, industrialization, and modern agriculture, the contradiction between supply and demand of water resources in the lower reaches of the Fen River continues to intensify, and the ecological water use of the river channel is greatly occupied. Coupled with problems such as pollution accumulation, river hardening, and overexploitation of groundwater, the functions of the aquatic ecosystem continue to degrade, and ecological chaos such as seasonal flow interruption, substandard water quality, and decline of aquatic biological communities have occurred.

In recent years, Shanxi Province has comprehensively promoted the ecological restoration and treatment project of the Fen River. Through a series of measures such as external water diversion and replenishment, pollution source remediation, and comprehensive river management, the water quality in the lower reaches of the Fen River has steadily improved, and the water quality at the Yellow River section has reached the Class III standard. However, there are still problems in the region, such as uneven spatial and temporal distribution of ecological flow, difficulty in ensuring basic flow during the dry season, insufficient systematic water ecological restoration, and prominent conflicts between ecology and production water use. Based on this, this article focuses on the characteristics of the lower reaches of the Fen River Basin, sorts out

the existing problems of water ecology, constructs an ecological flow guarantee system and integrated restoration plan, improves the long-term governance mechanism of the basin, and provides practical basis for improving the quality and efficiency of the Fen River Basin's ecology and protecting the Yellow River Basin's ecology.

2. Overview of the Study Area and Current Situation of Water Ecology

2.1 Overview of the Study Area

The study area of this paper is the lower reaches of Fenhe River, starting from Linfen in the north, passing through Houma, Xinjiang, Jishan, Hejin and other counties and cities, and reaching the section of Miaoqian village in Wanrong County into the Yellow River in the south. The total length of the river is about 170km, which is located at the end of Fenhe basin, belonging to the warm temperate zone semi-arid continental monsoon climate. The precipitation distribution in the region is extremely uneven. The flood season is mainly from July to September. The rainfall is centralized and rainstorm is frequent, and the flood runoff accounts for more than 60% of the total annual amount; During the dry season in winter and spring, the precipitation is scarce, and the natural incoming water of the river course decreases sharply.

The lower reaches of Fenhe River is a typical resource-based water shortage area. The local water resources endowment is poor, and the per capita water resources are far lower than the national average. The regional industries are mainly agricultural planting, coal chemical industry and light industry manufacturing. There is a large demand for agricultural irrigation water, industrial production water and urban and rural domestic water. The development and utilization rate of river water resources far exceeds the ecological reasonable threshold. At the same time, there are many regional tributaries, such as the Huihe River and Wenyu River, which run through the urban farmland and are the main channels for pollutant input and have a significant impact on the ecological environment of the main stream.

2.2 Core Ecological Issues

First, the ecological flow is insufficient and the temporal and spatial distribution is unbalanced. The core inducement is the attenuation of natural

runoff and the occupation of artificial water intake. The natural base flow in the lower reaches of the Fenhe River is very low during the dry season. In history, the river section from Xifan to Miaoqian into Huangkou has experienced seasonal flow interruption for many times. At present, the regional control standard is the ecological base flow of 5m³/s in the Xifan miaoqian section and the ecological flow of 1m³/s at the Yellow River inlet section. However, in dry years, the natural water can not meet the ecological needs, and it is completely dependent on artificial water supplement to maintain the continuous flow of the river. At the same time, the flow in flood season is concentrated, the flood peak is too high, the flow in dry season drops suddenly, the extreme hydrological process leads to the poor stability of aquatic habitat, and the self-healing ability of river ecosystem continues to weaken.

Second, the pollution superposition effect is significant, and the pressure of water quality control is high. The pollution in the lower reaches of Fenhe River presents the characteristics of "point source+non-point source+sediment" compound pollution. Urban domestic sewage and industrial park wastewater are the main point source pollution. Some old sewage outlets are not thoroughly treated, and there are intermittent excessive discharge problems; The loss of chemical fertilizers and pesticides in agricultural planting areas and the direct discharge of water from farmland are the main causes of water quality deterioration in flood season; The river sediment formed by long-term pollution deposition accumulates a large amount of nitrogen, phosphorus and organic matter, and the flow scours and disturbs the sediment in flood season, resulting in secondary pollution and short-term fluctuation of water quality exceeding the standard.

Third, the river channel is seriously artificial and the habitat structure is single. In the past, in the process of flood control, the river channel was cut and straightened, and the embankment was fully hardened, which completely changed the natural river channel shape. The structure of natural river bend, shoal and deep pool disappeared, the floodplain and waterfront wetland shrank in a large area, and the hydraulic conditions of the river became unitary. The hard embankment blocks the material exchange and energy cycle of the land and water ecosystem, the coverage of aquatic vegetation has decreased

significantly, the habitat of fish and benthos has been fragmented, the biodiversity has been continuously reduced, the river only retains the functions of flood discharge and water delivery, and the ecological service function has been seriously degraded.

Fourth, the competition of water resources is fierce, and the groundwater ecology is damaged. The agricultural irrigation system in the lower reaches of Fenhe River is developed, and the demand for irrigation water is large. The groundwater has been overexploited for a long time, forming a regional groundwater overexploitation area. The continuous decline of groundwater level has destroyed the two-way recharge mechanism between surface water and groundwater, weakened the lateral water replenishment capacity of the river, and further exacerbated the problem of water shortage in the river during the dry season. Ecological water, agricultural water, industrial water and domestic water are competing in many ways, and the contradiction of water resources scheduling is particularly prominent in dry years.

3. Construction of Ecological Flow Guarantee System in the Lower Reaches of Fenhe River

3.1 Scientific Accounting of Ecological Flow

Ecological flow is the core foundation to ensure the basic function of river ecosystem. In this paper, combined with the hydrological characteristics and ecological needs of the lower reaches of Fenhe River, the Tennant method and wet week method are used to calculate the ecological flow by time and target, and a three-level flow guarantee system of "base flow+sensitive period flow+pulse flow" is constructed. In the dry season, the goal is to maintain the continuous flow of the river channel and protect the basic aquatic habitat, and to verify and stabilize the ecological base flow; During the sensitive spawning period of fish in spring, increase the river flow and water depth to meet the breeding and habitat needs of aquatic organisms; During the flood season, the ecological pulse flood is appropriately reserved to simulate the natural hydrological process, so as to realize beach overflow, sediment renewal, wetland water replenishment, and restore the natural ecological rhythm of the river. Through multi method coupling accounting, the limitation of a single algorithm is avoided, and the flow standard is ensured to fit the regional ecological

reality.

3.2 Multi Water Source Joint Dispatching Guarantee Mechanism

Relying on the water resources allocation pattern of "six rivers to Fenhe" in Shanxi Province, we will integrate the external water diversion sources such as Wanjiazhai Yellow River Diversion Project, Fenhe Reservoir II, boyekou reservoir, Yumenkou water pumping eastward expansion and local reservoir water sources, and build a normalized ecological water replenishment system in the lower reaches of Fenhe River. In view of the short board of the spatial-temporal distribution of downstream water resources, the refined scheduling mode of "total amount control, monthly scheduling, ten day fine-tuning, and emergency replenishment" is implemented. The contradiction between supply and demand of water resources is prominent in the peak irrigation season and the dry season. The water intakes along the line are strictly controlled, illegal water intakes and excessive water intakes are strictly controlled, and the ecological base flow of river channels is given priority; In dry years, the emergency water replenishment plan was launched to ensure that the flow at the Yellow River inlet section was stable and up to standard.

At the same time, we should strengthen the control of water rights, clarify the rigid share of ecological water use, bring ecological water use into the unified allocation system of regional water resources, and rely on the online monitoring system to achieve real-time monitoring of water intake, water replenishment and flow. Simultaneously promote the comprehensive treatment of groundwater overexploitation, gradually raise the groundwater level by replacing groundwater with surface water for irrigation, restore the connection mechanism between surface water and groundwater, and improve the ecological water replenishment capacity of the river from the root. At present, Yumenkou water lifting and eastward expansion project can supplement 14.46 million m³ of ecological water for the lower reaches of Fenhe River every year. The Beizhao connection section project has specially guaranteed the ecological base flow of the lower reaches, effectively alleviating the risk of river interruption in the lower reaches.

4. Integrated Technology System of Water

Ecological Restoration in the Lower Reaches of Fenhe River

Following the concept of integrated management of mountains, rivers, forests, fields, lakes, grass and sand and the solution based on nature, abandoning the traditional single project management mode, building a five in one water ecological restoration technology system of "source control and pollution reduction - Habitat Remodeling - wetland purification - biological reconstruction - long-term management and protection", and realizing the transformation from water quality improvement to comprehensive restoration of water ecosystem.

4.1 Systematic Treatment of Global Pollution Sources

Pollution control is the premise of water ecological restoration, and the implementation of point source, non-point source and endogenous collaborative governance. In terms of point source pollution, comprehensively investigate and rectify the sewage outlets into the river, ban illegal sewage outlets, standardize the discharge standards of compliant sewage outlets, promote the upgrading and reconstruction of urban sewage treatment plants, and ensure that the tail water meets the discharge standards; Industrial enterprises strictly implement the pollutant discharge permit system, promote cleaner production, and strictly control the total amount and concentration of wastewater discharge. In terms of non-point source pollution, we should optimize the agricultural planting structure, reduce the use of chemical fertilizers and pesticides, promote the ecological planting mode, build vegetation buffer zones on both sides of the river, and intercept and purify the returning water from farmland; We will improve the collection and treatment system for rural domestic sewage and garbage, and solve the problem of rural non-point source pollution. In terms of endogenous pollution, it is required to accurately carry out river dredging, selectively remove highly polluted sediment, reduce secondary pollution of sediment, and retain moderate natural sedimentation to maintain the stability of river ecological base.

4.2 Reconstruction of River Habitat Form

In view of the problems of artificial river and single habitat, ecological river reconstruction was carried out. The hardened embankment is ecologically transformed and replaced with

gabion, ecological blanket, permeable slope protection and other ecological revetment structures to restore the ecological function of the land water transition zone; Restore the natural shape of the river channel, moderately restore the alternating structure of river bends, shoals and deep pools, remove the dikes and cofferdams illegally encroaching on the river channel, and restore the flood discharge, water storage and ecological conservation functions of the beach. Through the construction of ecological submerged dams, overflow weirs and other small ecological projects, the flow velocity and water depth of the river are adjusted, and diversified hydraulic conditions are created to provide suitable habitats for different aquatic organisms and restore the natural hydrological and geomorphological characteristics of the river.

4.3 Ecological Purification and Restoration of Riverside Wetland

Relying on the floodplain of the lower reaches of the Fenhe River and the idle area of the tributary estuaries, surface flow wetlands, subsurface flow constructed wetlands, and estuarine ecological wetlands will be constructed to further purify the incoming water from tributaries, farmland backwater, and river tail water, and further reduce the nitrogen and phosphorus pollutant loads. Construct the arbor shrub Grass Compound waterfront vegetation zone, screen the reed, cattail, *Acorus calamus* and other native aquatic plants, and form a multi-layer vegetation purification system, which can not only intercept pollutants and conserve water sources, but also provide habitat for birds and aquatic organisms, repair the waterfront ecological corridor function, and improve the self purification ability of the river.

4.4 Reconstruction of Aquatic Community

In combination with the historical community structure of aquatic organisms in the lower reaches of the Fenhe River, local fish and benthos are put in to improve the aquatic food chain and restore the ecological balance of the water body. Strictly control alien invasive species, regularly carry out biological monitoring, and avoid the risk of biological invasion. At the same time, relying on the dynamic regulation of ecological flow, the hydrological conditions during the critical period of spawning, migration and growth of aquatic

organisms are guaranteed, providing basic guarantee for the restoration of biological communities, gradually improving the biodiversity of river channels, and realizing the self maintenance and self repair of aquatic ecosystem.

5. Existing Governance Difficulties and Optimization Countermeasures

5.1 Existing Core Difficulties

First, the multi-objective trade-off of water resources is difficult. The competition between production, living and ecological water in the lower reaches of Fenhe River is prominent. The cost of ecological water supplement in dry years is high and the scheduling pressure is high. How to maximize the benefit of water resources and balance economic development and ecological protection is the core problem of current governance. Second, the coupling treatment of flow and water quality is insufficient. The river flow can be improved only by artificial water supplement. If the pollution load control of tributaries is not in place, the problem of water quality fluctuation will still occur, and the coordination between flow control and pollution control is insufficient. Third, there is a lack of long-term management and protection mechanism for restoration projects. The funds for the late management and protection of ecological wetlands, vegetation riparian zones and other ecological projects are insufficient and the responsibility is unclear, which is prone to degradation and rebound. Fourth, the ecological monitoring and assessment system is not perfect, and there is a lack of quantitative water ecological health assessment standards, which makes it difficult to accurately determine the restoration effect and optimize the treatment scheme.

5.2 Long-Term Governance Optimization Countermeasures

First, build an intelligent water resources scheduling system. Build a big data monitoring platform for hydrology, water quality and water use, and establish a dynamic ecological flow scheduling model in combination with weather forecast, crop irrigation cycle and ecological demand, so as to achieve precise scheduling by season and river section, balance water consumption contradiction to the maximum extent, and reduce the cost of ecological water

replenishment. Improve the rigid guarantee system for ecological water use, strictly control unreasonable water intake, and compact the responsibility for ecological flow control in various regions.

Second, promote the coordinated treatment of water quantity and quality. Combine the ecological flow regulation with pollution load control in depth, establish a total pollution load control mechanism for tributaries, focus on strengthening the control of non-point source pollution in the flood season, realize "pollution control by water and water purification", and fundamentally stabilize the river water quality.

Third, improve the long-term management and protection and capital guarantee mechanism. Clarify the management and protection subjects of ecological restoration projects, establish a management and protection mode of government led, social participation and market-oriented operation, set up special ecological management and protection funds, and promote cross regional ecological co construction and sharing by relying on the ecological compensation mechanism, so as to prevent the degradation and rebound of ecological projects.

Fourth, improve the ecological monitoring and evaluation system. Build a comprehensive monitoring network of "hydrology - water quality - sediment - Biology", establish a quantitative assessment index system for water ecological health, regularly carry out the assessment of remediation effectiveness, implement adaptive dynamic governance, and continuously optimize the remediation scheme.

6. Conclusion

The core source of water ecological degradation in the lower reaches of Fenhe River is the imbalance of water resources development and utilization and the lag of ecological protection. The shortage of ecological flow is the primary bottleneck restricting the regional water ecological restoration. Pollution accumulation, habitat destruction and biological degradation are the core problems. By combing the ecological status of the lower reaches of the Fenhe River, this paper constructed a scientific ecological flow accounting and multi water source joint scheduling guarantee system, integrated and formed an integrated water ecological restoration technology path of source control and pollution reduction, habitat remodeling, wetland purification and biological

reconstruction, and specifically solved the contradiction between supply and demand of regional water resources and the fragmentation of ecological governance.

The research shows that the ecological restoration of the lower reaches of Fenhe River must adhere to the governance idea of "flow guarantee as the basis, source control and pollution reduction as the core, ecological remodeling as the key, and long-term management and protection as the support", abandon the single project governance mode, and promote the systematic, refined and normalized governance of the basin. In the future, it is necessary to continue to optimize the intelligent water resources dispatching system, deepen cross regional collaborative governance, improve the ecological compensation and long-term management and protection mechanism, continue to improve the stability and service function of the water ecosystem in the lower reaches of the Fenhe River, build a strong ecological security barrier in the middle reaches of the Yellow River, and help the ecological protection and high-quality development of the Yellow River Basin.

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