The impact of hydraulic engineering on river ecosystems and ecological scheduling strategies

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Abstract. The construction of water conservancy projects has a profound impact on the hydrological situation, hydraulic characteristics, habitat environment of aquatic organisms, and water quality conditions of river ecosystems. Research and analyze the specific impact of water conservancy engineering on river ecosystems, and explore scientifically reasonable ecological scheduling strategies to reduce the adverse effects of engineering on ecosystems. The research content includes key factors such as changes in hydrological conditions, adjustment of hydrodynamic characteristics, riverbed evolution, and water quality changes. Based on ecological flow regulation, hydrodynamic optimization, restoration of aquatic habitats, and water quality management, ecological scheduling technology solutions are proposed. The research results indicate that reasonable ecological scheduling can effectively improve the ecological environment of rivers, enhance the quality of aquatic habitats, and optimize water resource utilization efficiency.

Keywords: water conservancy engineering, River ecosystem, Ecological scheduling, Ecological flow regulation.

1. Introduction

Water conservancy engineering not only ensures flood control safety, provides water resource allocation, and supports economic development, but also has a profound impact on the hydrological situation, hydraulic characteristics, and habitat environment of aquatic organisms in river ecosystems. Facilities such as dams, reservoirs, and water diversion projects have altered the flow process and hydrodynamic structure of natural rivers, leading to habitat fragmentation, water quality deterioration, and biodiversity decline in aquatic ecosystems. Due to improper long-term water regulation, some rivers have experienced ecological problems such as interruption, sedimentation, and eutrophication of water bodies, posing a threat to regional water environment security. Study the specific impact mechanism of water conservancy engineering on river ecosystems, and explore ecological scheduling strategies based on ecological flow regulation, hydrodynamic regulation, and habitat restoration of aquatic organisms.

2. Analyze the impact of water conservancy projects on river ecosystems

2.1. Changes in hydrological conditions and their ecological effects

Water conservancy projects play an important role in water resource allocation, flood control, and hydropower generation, but their operation can cause significant changes in the hydrological situation of the watershed, thereby affecting the stability of river ecosystems. The construction of water conservancy projects such as reservoirs and dams has changed the natural flow process of many rivers, causing an increase in flow during the dry season and a decrease in flow during the wet season, resulting in periodic changes in water level fluctuations and affecting the reproductive rhythm and habitat environment of aquatic organisms. The regulation and storage function of cascade reservoirs weakens natural flood peaks, reduces downstream river flow, leads to the shrinkage of river wetlands, and the degradation of some habitat functions. The typical characteristics of hydrological changes can be quantitatively analyzed based on years of hydrological monitoring data. Taking the Three

Gorges Reservoir as an example, after the operation of a regulating reservoir, different hydrological parameters undergo significant changes before and after dispatch, as shown in Table 1:

Table 1. Specific hydrological changes in rivers before and after water conservancy project scheduling

index	Before scheduling	After scheduling	trend
Annual average flow rate (m ³/s)	250	190	decline
Annual minimum flow rate (m ³/s)	80	45	decline
Annual maximum flow rate (m ³/s)	900	600	decline
Water level variation (m)	3.2	1.5	reduce
Proportion of dry season flow	20%	35%	increase

The average annual flow and maximum annual flow after scheduling both show a downward trend, the water level amplitude decreases, and the hydrodynamic processes of the river are suppressed. This change reduces the sediment transport capacity of the river channel, which may lead to sedimentation and cause riverbed evolution, thereby affecting fish spawning grounds. The proportion of flow during the dry season increases, which to some extent ensures the demand for water resource utilization. However, the seasonal hydrological rhythm of the ecosystem is disturbed, affecting the life cycle adaptability of aquatic organisms.

2.2. Impact of Changes in Hydraulic Characteristics on Aquatic Organisms

The changes in hydraulic characteristics will directly affect the living environment of aquatic organisms in the local water bodies. The development of reservoirs and cascades leads to a steady flow of water and a decrease in velocity, which is not conducive to the spawning of migratory fish species that require high velocity environments. During the flood season, the erosion ability of the river is weakened, leading to an increase in sediment particles and affecting the living conditions of certain benthic organisms. The waterway regulation project changes the dynamic structure of water flow, causing an increase in local flow velocity and resulting in damage to aquatic vegetation in certain water areas, thereby reducing the habitat density of aquatic animals. Taking the behavior of fish migration as an example, changes in flow velocity will determine the feasibility of fish migration. Before the construction of water conservancy projects, the average flow velocity in the downstream section of the Three Gorges in spring was 1.2 m/s, which was suitable for the migration needs of most fish species. After the operation of the water conservancy project, the flow velocity of the river section decreased to 0.5 m/s, and some migratory fish were unable to complete their upstream migration due to insufficient flow velocity, resulting in a decrease in population size. For spawning habitats that rely on high flow rates, such as catfish, reproduction is limited and population numbers sharply decrease after reservoir regulation. The low flow velocity environment also increases the risk of eutrophication, excessive reproduction of phytoplankton affects water transparency, deteriorates underwater lighting environment, and affects the stability of aquatic ecosystems. In the cascade reservoir system, the sheer force of water flow weakens, the population structure of planktonic animals' changes, some large planktonic animals decrease, and small planktonic organisms dominate, leading to changes in the food chain structure. The cut-off effect of the dam has intensified the biological isolation of certain river sections and reduced species exchange between different water bodies. The change in flow velocity also affects the distribution of aquatic plants. Some aquatic plants that rely on high flow velocity environments have limited growth after the completion of water conservancy projects, gradually leading to the dominance of species that prefer still water environments, thereby affecting the diversity and stability of the entire river ecosystem.

3. Ecological Dispatch Technologies and Their Applicability Analysis

3.1. Basic Principles and Objectives of Ecological Scheduling

Ecological scheduling is a water resource regulation method based on the demand of river ecosystems, and its basic principle is to regulate the outflow of water conservancy projects such as reservoirs and dams. During the operation of water conservancy projects, significant changes occur in the hydrological conditions, hydrodynamic characteristics, and physical habitat structure of rivers, leading to habitat degradation of aquatic organisms, decreased species diversity, and damage to ecosystem functions. The core goal of ecological regulation is to restore or optimize the ecological environment of rivers, ensure the survival conditions of key aquatic organisms, while also considering the multiple needs of water resource supply, flood control safety, and hydropower utilization. Migratory fish are highly sensitive to seasonal changes in water flow and require specific flow velocity and water level conditions to lay eggs, hatch, and swim upstream. Benthic invertebrates have a strong dependence on water flow stability, sediment characteristics, and dissolved oxygen concentration. Ecological regulation should avoid excessive flow velocity or sudden changes in flow rate to reduce the impact on the sediment environment. The growth of aquatic vegetation is comprehensively affected by water flow disturbance, water depth changes, and water quality conditions. Ecological regulation should ensure a suitable hydrodynamic environment and maintain the stability of vegetation communities. The microbial community is the foundation of aquatic ecosystems, and its habitat is mainly influenced by water exchange capacity and water quality. The scheduling strategy needs to ensure a reasonable frequency of water exchange and supply of dissolved oxygen to maintain a healthy aquatic microbial ecological structure.

3.2. Ecological flow regulation methods

Ecological flow regulation is one of the core measures of ecological regulation, mainly adjusting the outflow mode of reservoirs and dams to ensure that rivers maintain a reasonable flow process in different seasons and hydrological conditions, in order to ensure the stability of aquatic ecosystems. The key methods of ecological flow regulation include minimum ecological flow control, variable ecological flow regulation, and flood pulse restoration. The minimum ecological flow control refers to maintaining the minimum flow rate of the river during the dry season to avoid deterioration of the living conditions of aquatic organisms. Adjusting ecological flow based on the growth and reproduction cycles of aquatic organisms, simulating natural hydrological rhythms, and optimizing flow processes. The increase in flow during the dry season after scheduling reduces the risk of habitat reduction for aquatic organisms due to low flow. The increase in flow during the spawning period provides a suitable breeding environment for fish. Peak shaving measures during flood periods reduce erosion and damage to river vegetation and benthic organisms. Fine tuning of flow during normal water periods helps maintain stable hydrodynamic conditions and promote a virtuous cycle of aquatic ecosystems.

3.3. Hydrodynamic regulation and habitat restoration of aquatic organisms

Hydrodynamic regulation relies on optimizing flow velocity, flow state, and water level changes to improve the stability of aquatic habitats. During the operation of water conservancy projects, changes in water flow structure led to the degradation of some habitat functions, such as intensified sedimentation in low velocity areas and excessive turbulent water flow during flood periods. The core measures of hydrodynamic regulation include artificial water flow regulation, lateral flow recovery, and velocity gradient optimization. The artificial water flow regulation of water gates and reservoirs adjusts the local hydrodynamic characteristics to restore a suitable flow structure. Lateral flow restoration utilizes ecological embankments, ecological diversion channels, and other measures to improve water exchange capacity and enhance habitat connectivity. The effect of hydrodynamic regulation can be verified by analyzing the flow field data. The changes in key ecological factors

before and after hydrodynamic regulation in a section of the downstream of the Three Gorges Reservoir are shown in Table 2

Table 2. Changes in habitat characteristics of aquatic organisms before and after hydrodynamic regulation

index	Before regulation	After regulation	Ecological effect
Average flow velocity (m/s)	0.3	0.8	Suitable for migratory fish migration
Maximum shear force (N/m ²)	0.05	0.12	Enhance sediment stability, beneficial for benthic organisms
Turbulence intensity	low	centre	Improve water mixing and increase dissolved oxygen
Bottom sediment deposition rate (kg/m ²/year)	5.4	2.1	Reduce sedimentation and optimize habitats

After hydrodynamic regulation, the average flow velocity of the river increases, providing suitable migration conditions for migratory fish. The increase in maximum shear force makes sediment deposition more stable, which is beneficial for the survival of benthic invertebrates. The increase in turbulence intensity enhances the mixing capacity of water bodies, promotes the supply of dissolved oxygen, and improves the aquatic ecological environment.

4. Engineering Practice and Optimization Strategies for Ecological Scheduling

4.1. Typical ecological dispatch practice cases in river basins

The ecological operation practice of the Three Gorges Reservoir is an important case of optimizing ecological management in water conservancy engineering. The operation of the Three Gorges Reservoir has played an important role in flood control, power generation, navigation and other aspects, but its operation mode has had an impact on the ecosystem in the middle and lower reaches of the Yangtze River, especially on the natural reproduction of the four famous domestic fishes. The reproduction of the four famous domestic fishes depends on a certain flow pulse and a suitable flow rate environment. The cascade operation of the reservoir weakens the natural flood peak in the downstream, leading to the reduction of fish spawning grounds, shortening the drifting distance of spawning seedlings, and affecting population replenishment. To improve this problem, the Three Gorges Reservoir has implemented ecological regulation experiments since 2011, increasing the discharge flow in the short term, simulating the natural water rise process, and stimulating fish spawning behavior. During the ecological regulation period, the Three Gorges Reservoir increased the outflow flow to 25000 cubic meters per second during the peak period of fish breeding, forming a water flow pulse that caused the water level in the lower reaches of Yichang to rise by 0.5 meters and the flow velocity to increase by 0.2 meters per second, creating a suitable breeding environment. Monitoring data shows that after ecological regulation, the natural reproduction scale of the four famous domestic fishes in the mainstream of the Yangtze River has significantly increased, the density of eggs has increased 2.5 times compared with the year without regulation, and the survival rate of eggs has increased by about 30%, effectively promoting the recovery of fish resources in the Yangtze River.

4.2. Ecological scheduling strategy based on multi-objective optimization

The ecological scheduling strategy based on multi-objective optimization needs to optimize the hydrological situation of rivers while ensuring flood control safety, meeting water demand, and maintaining the benefits of hydropower generation, in order to restore the stability of aquatic ecosystems. Optimization strategies include dynamic ecological flow control, ecological water level regulation, and precise hydrodynamic regulation. Dynamic ecological flow control adjusts the flow process according to the ecological needs of different seasons, avoiding ecological imbalance caused

by a single fixed flow. Optimizing reservoir scheduling for ecological water level regulation, maintaining appropriate water level fluctuations, and ensuring the integrity of wetland habitats. Accurate hydrodynamic regulation combined with water flow model simulation analysis, adjusting the flow velocity distribution of key sections, and optimizing the habitat environment of aquatic organisms. The optimized ecological scheduling measures have shown positive ecological benefits in multiple indicators, as shown in Table 3:

Table 3. Changes in Key Ecological Indicators Before and After Ecological Scheduling Optimization

index	Before optimization	After optimization	Ecological improvement
Average flow velocity (m/s)	0.6	1	Improve the success rate of fish migration
Area of spawning ground (km ²)	120	180	Promote fish reproduction
Density of benthic organisms (individuals/m ²)	500	850	Enhance aquatic biodiversity
Wetland water level variation (m)	0.3	0.8	Maintain wetland vegetation growth

After optimization, the hydrodynamic conditions of the river have significantly improved, and the increase in flow velocity promotes the natural migration of migratory fish. The expansion of spawning grounds provides more suitable breeding conditions, and the increase in benthic organism density reflects the restoration of habitat quality. The optimization of wetland water level fluctuations enhances the ecological function of the water land ecotone.

5. Conclusion

Water conservancy projects not only regulate water resources, ensure flood control safety, and promote economic development, but also have a profound impact on river ecosystems, mainly reflected in changes in hydrological conditions, adjustments in hydrodynamic characteristics, and changes in the habitat environment of aquatic organisms. Ecological scheduling, as an important means of mitigating the negative impacts of engineering, has effectively restored the stability of river ecosystems by optimizing flow processes, hydrodynamic structures, and habitat conditions. Research has shown that reasonable ecological scheduling strategies can improve the living environment of aquatic organisms, enhance biodiversity, and strengthen the ecological functions of rivers, providing a scientific basis for sustainable management of water resources.

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