A study on the ecological water requirement in the Xin' an county section of the Jian river channel

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Abstract: Taking the urban section of Xin' an County in the Jian River as an example, this study statistically analyzed hydrological data from the Xin' an Hydrological Station from 1959 to 2010.It used the Tennant method from hydrology and the R2CROSs method from hydraulics to analyze and calculate the basic ecological water requirement within the river channel. Additionally, the study calculated the water requirements for river water purification, river evaporation and seepage, and the minimum sediment transport in the river channel. Following the principle of non-redundant calculation, the maximum value among these water requirements was taken, resulting in an ecological water requirement of 3010.0 m^3/s for the urban section of the Jian River. This water volume is the optimal requirement for restoring the ecological structure and functional health of the river section. This result has important reference significance for the sustainable use of water resources in the river channel and the maintenance of the river ecosystem balance.

Keywords: Jian River, Xin' an County, River Channel, Ecological Environment, Water Requirement

1. Introduction

The Jian River originates in Guanyin Hall, Shan County, western Henan Province, and flows through Mian chi, Yima, Xin' an, and the urban area of Luoyang, eventually joining the Luo River in Luoyang. It then flows into the Yellow River via the Yi Luo River. The main stream is 112 km long, with a drainage area of 1,349 km^2, forming a typical dendritic river system. The climatic characteristics of the basin are described as "spring drought with little rain and frequent sandstorms; hot summer with concentrated rainfall; clear autumn with long sunshine; and cold winter with scarce rain and snow." The terrain and topography within the basin are highly variable, with an average annual rainfall of 680 mm. Rainfall is unevenly distributed in time and space, with the majority of precipitation occurring in July and August. The flood characteristics are high flood peaks, large flood volumes, short durations, and rapid rises and falls.

The ecological water requirement within the river channel is essential for maintaining the health of the river ecosystem and is of significant importance for the structure, function, and morphology of the river ecosystem. From a structural and functional perspective, the ecological water requirement within the river channel is an organic whole composed of multiple variables, including basic ecological water requirement, sediment transport water requirement, evaporation and seepage water requirement, purification water requirement, ecological landscape water requirement, and navigation water requirement[1].The Jian River is located in an arid and water-scarce region, and there are no navigation requirements for this section of the river. Therefore, this calculation temporarily does not consider the ecological landscape water requirement and navigation water requirement. The ecological water requirement for the river environment follows the principle of non-redundant calculation, that is, the maximum value among the remaining four water requirements is taken as the ecological water requirement for the urban section of the Jian River.

2. Basic ecological water requirement in the river channel

Currently, widely used methods for calculating the basic ecological water requirement in river channels mainly include hydrological methods, hydraulic methods, habitat evaluation methods, and holistic analysis methods [2]. Based on the available data, we selected the Tennant method from hydrology and the

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R2CROSs method from hydraulics to calculate the basic ecological water requirement for the urban section of the Jian River. The results from these two methods were cross-validated and compared to determine a flow rate that more accurately reflects the actual conditions. Specifically, the hydrological method uses natural runoff to calculate the basic ecological water requirement, while the hydraulic method employs the measured flow rates from the Xin' an Hydrological Station in recent years for the calculation.

According to the statistical data from the Xin' an Hydrological Station from 1959 to 2010,the average annual rainfall over multiple years was 620.23 mm, and the average annual runoff volume was 67 million m^3.From 1959 to 1970,the average annual water volume at the Xin' an Hydrological Station was 97 million m^3;from 1971 to 1990,it was 82 million m^3;and from 1991 to 2010,it was 36 million m^3.It can be observed that the average annual water volume at the Xin' an section of the Jian River Basin has shown a continuous downward trend over the years. However, the rainfall has not changed significantly in recent years, with the average annual rainfall at the Xin' an station for the three time periods being 608.69 mm,660.49 mm, and 584.64 mm, respectively. After the 1970s, the Yellow River Basin gradually began to develop in terms of industry and agriculture, and entered a period of rapid development in the 1990s. Therefore, the reduction in water inflow is mainly due to the rapid development of industry and agriculture in recent years, leading to an increasing demand for water. Hence, the runoff series from 1959 to 1970 at the Xin' an station can essentially represent the natural inflow series unaffected by human activities, meeting the requirements for calculation using the hydrological method.

2.1. Tennant method (Tennant approach)

The ecological flow in a river channel exhibits seasonal characteristics with higher water requirements during the wet season and lower requirements during the dry season, showing periodic changes. This is an important feature of the ecosystem, which has evolved over a long period as organisms adapt to their environment. The river ecosystem has significant seasonal variations, divided into the pre-flood period, flood season, and post-flood dry season, collectively referred to as ecological hydrological seasons. During different ecological hydrological seasons, the ecological demands of the river ecosystem are markedly different.

Pre-flood period: River water levels rise, flow velocity increases, and water temperature rises. Organisms emerge from their dormant state during the dry season and become active again. Fish begin to spawn, and their larvae hatch.

Flood season: High flow rates enrich the river habitat, promoting rapid biological growth. Floods enhance the river's capacity for sediment transport and nutrient delivery downstream, maintaining connectivity between the river and wetlands or lakes.

Post-flood dry season: River water levels decrease, flow velocity slows down, water temperature drops, and food becomes scarce. River organisms gradually enter a dormant state, and the ecosystem enters a winter hibernation period.

Flood season runoff can maintain the overall dynamic balance of the river system and provide the periodic high-flow water conditions needed by the river. If the ecological water requirements during the flood season are not met for an extended period, the riverbed will become silted up and elevated. The river, wetlands, and floodplains will then become isolated and fragile ecological patches, susceptible to disturbances and destruction. Therefore, it is necessary to meet the basic ecological water requirements for both the flood season and the non-flood season (or the wet season and the dry season).

In southern China, the ecological base flow during the flood season is generally met. However, in the water-scarce northern regions, it is common for the ecological base flow during the flood season to be unmet. The Jian River is located in the northern region, so its basic ecological water requirement should be determined separately for the non-flood season and the flood season (or the wet season and the dry season).

The Tennant method is the most commonly used hydrological method for calculating basic ecological water requirements and is suitable for any river with seasonal variations. Based on a large amount of measured data, it summarizes the relationship between different time periods, different flow rate percentages, and the corresponding ecological conditions within the river channel (see Table 1).

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Table 1 Relationship between River Flow and Ecological Environmental Conditions [3]

Description of Ecological and Environmental Conditions	Recommended Flow Standards (Percentage of Annual Average Flow, %)	
	General Water Use Period (November-June)	Fish Spawning and Juvenile Period (July-October)
Maximum	200	200
Optimal Flow	60~100	60~100
Excellent	40	60
Very Good	30	50
Good	20	40
Beginning to Deteriorate	10	30
Poor or Minimum	10	10
Very Poor	<10	<10

In the calculation, the basic ecological water requirement of the Jian River is divided into the dry season (November to June) and the wet season (July to October). The basic ecological water requirement for different periods within the river channel is determined as a percentage of the annual average natural runoff. By summing up the values for the entire year, the annual basic ecological water requirement for the urban section of the Jian River can be obtained. The calculation formula is as follows:

$$W_r = 24 * 3600 * \sum_{i=1}^{12} M_i * Q_i * P_i$$

In the formula:

• W_r—The basic ecological water requirement to maintain certain functions of the river channel under average multi-year conditions, in cubic meters(m^3).

• M_i—The number of days in the month, in days.

• Q_i—The average monthly flow rate for the month over multiple years, in cubic meters per second(m^3/s).

•P_i—The ecological water requirement percentage for the month, in percent (%).

According to the empirical parameters provided by the Tennant method, the basic ecological water requirement during the flood season is set at 40%of the average annual water volume over multiple years, while the basic ecological water requirement during the non-flood season is set at 20%of the average annual water volume. These percentages are designed to maintain the river channel's ecological environment in a good condition and prevent ecological degradation.

Taking the measured data from the urban section of Xin' an County in the Jian River Basin before the 1970s as the natural flow, the basic ecological water requirements for each month calculated using the Tennant method are shown in Table 2.Specifically,the ecological flow for the non-flood season(November to June)of the Jian River is 0.48 m^3/s, and for the flood season(July to October),it is 1.88 m^3/s. Therefore, the total basic ecological water requirement within the river channel is 30.10 million m^3, of which the non-flood season basic ecological water requirement is 10.083 million m^3, and the flood season basic ecological water requirement is 20.017 million m^3.

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Table 2 Calculation of Basic Ecological Water Requirement in the River Channel (Tennant Method)

Category	January	February	March	April	May	June
Basic Ecological Water Requirement (10,000 m³)	126.6	106.7	112.4	112.0	121.4	123.2
Ecological Flow (m³/s)	0.47	0.44	0.42	0.43	0.45	0.48
Category	July	August	September	October	November	December
Basic Ecological Water Requirement (10,000 m³)	577.2	612.4	423.2	388.8	172.7	133.3
Ecological Flow (m³/s)	2.16	2.29	1.63	1.45	0.67	0.50

2.2. R2CROSs method

The living space for aquatic organisms is the most fundamental condition for their survival. The river channel ecosystem hosts a variety of organisms, including algae, phytoplankton, zooplankton, macrophytes, benthic animals, and fish. After determining the minimum spatial requirements for all organisms in the river channel ecosystem, the maximum of these values is taken as the minimum spatial requirement for organisms in the river channel ecosystem. Since it is not possible to determine the minimum space required by each species, and considering that fish occupy a unique position in the aquatic ecosystem compared to other groups, fish are generally the top community in the aquatic ecosystem and are the primary target for fishing. As a top community, fish play an important role in the presence and abundance of other groups. Given the special role of fish in the river ecosystem and their sensitivity to living space, fish are considered as key species and indicator organisms [4].

The hydraulic elements that describe the living space for fish mainly include water surface width, average depth, maximum depth, flow velocity, cross-sectional area, and cross-sectional shape. The R2CROSs method, based on a large amount of field-measured data, has established the interrelationships among average depth, average flow velocity, and top width as habitat indicators, and has proposed the corresponding hydraulic parameters for minimum ecological flow in rivers of different scales, as shown in Table [5].

Table 3 Main Hydraulic Parameters of the R2CROSs Method

Top Width of River(m)	Top Width of River(m)	Average Water Depth(m)
0.3~6	0.003~0.06	0.30
6~12	0.06~0.12	0.30
12~18	0.12~0.18	0.30
18~31	0.18~0.30	0.30

In the calculation, based on the cross-sectional width of the Xin' an Hydrological Station, the hydraulic parameters required for ecological flow—average water depth and average flow velocity—are obtained from the table. Then, the basic ecological water requirement is determined based on the relationship between water depth, average flow velocity, and discharge established for that cross-section.

According to the analysis of the measured data from the Xin' an Hydrological Station since 1990, when the water frequency is 50%over the past 20 years, the average monthly flow rate within the river channel is 0.78 m³/s. Based on the analysis of the measured large cross-section results at the Xin' an station on the Jian River, the corresponding water surface width is 21.28 m.

Combining the measured data, the parameters in the R2CROSs method are selected as follows: top width of 18 m, average water depth of 0.18 m, and flow velocity of 0.3 m/s. The calculated basic ecological water requirement is 30.653 million m³.

Comparing the basic ecological water requirements calculated by the Tennant method and the R2CROSs method, which are 30.100 million m³ and 30.653 million m³, respectively, the results are quite close. The

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Tennant method, based on the characteristics of the Jian River as a seasonal river, separately analyzes and calculates the ecological water requirements for the flood season and non-flood season, considering the changes in ecological water requirements throughout the year, which is more in line with reality. The R2CROSs method, based on the survival space of aquatic organisms, establishes a hydraulic relationship and references measured cross-section data in parameter selection, resulting in a more reliable outcome that can be used to verify the results obtained by the Tennant method. Therefore, the calculation result of the Tennant method is selected as the basic ecological water requirement for the river section, which is 30.100 million m³.

3. Water requirement for river water quality purification

Due to the lack of data on the volume and quality of wastewater and Rebirth water discharged upstream, it is not possible to calculate the water requirement for river water quality purification using a water quality prediction model. However, the minimum monthly average flow rate method over the past ten years can be used to estimate the dilution and purification water requirement. This method is widely used in China and the calculated flow rate can meet the ecological water requirements for general river pollution prevention and water body self-purification.

The minimum monthly average flow rate method over the past ten years evolved from the 7Q10 method in hydrology. Since the 7Q10 method requires a high level of data in China, the minimum monthly average flow rate method over the past ten years was developed.

In the "Technical Principles and Methods for Formulating Local Water Pollutant Discharge Standards"(GB3838-83), it is stipulated that the minimum monthly average measured runoff of rivers over multiple years can be used as the water requirement for river dilution and purification. The calculation formula is:

$$W_b = \frac{T}{n}\sum_{i=1}^{n} Q_{imin}$$

In the formula:

W_b—The water requirement for river water quality purification, in ten thousand cubic meters(10000m³).

Q_{imin}—The minimum monthly average flow rate of the year, in cubic meters per second(m³/s).

T—The conversion coefficient, with a value of 365×24×60×60÷10⁴=3153.6.

n—The number of years for statistics, in years.

The measured flow rates from the Xin' an Hydrological Station from 2001 to 2010 are used as the natural flow for this river section. The minimum monthly average flow rates for each year are shown in Table 4.

Table 4 Minimum Monthly Average Flow Rates of Xin' an Hydrological Station over the Past Ten Years

Year	2000	2001	2002	2004	2005	2006	2007	2008	2009	2010
Flow	0.152	0.136	0.085	0.593	0.572	0.421	0.330	0.584	0.458	0.687

Based on the data in Table 4, using the minimum monthly average flow rate method over the past ten years, the ecological flow is calculated to be 0.381 m³/s, and the water requirement for water quality purification within the river channel is 12.017 million m³.

4. Water requirement for river evaporation and seepage

The water requirement for river evaporation and seepage consists of two parts: the water requirement for evaporation and the water requirement for seepage. The water requirement for evaporation is calculated based on the water surface area and the local average annual precipitation and evaporation over the years[7].The formula is as follows:

$$W_e = \begin{cases} (P-E)\times A & E > P \\ 0 & E < P \end{cases}$$

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In the formula:

W_e—Water requirement for river evaporation,in ten thousand cubic meters(万 m³).

P—Average annual precipitation over multiple years, in millimeters(mm).

E—Average annual evaporation over multiple years, in millimeters(mm).

A—Water surface area of the water body during the calculation period, in square meters(m²).

Based on the measured data from the Xin' an Hydrological Station, when the water frequency is 50%over the past 20 years, the water surface width is 21.35 meters. The length of the river section in the urban area of the Jian River is 4.5 kilometers. The calculated water surface area formed by the Jian River flowing through the urban section is 0.10 square kilometers. The monthly evaporation water requirements, calculated based on the average monthly precipitation and evaporation from 1991 to 2000 in Xin' an County, are shown in Table 5. By summing up the monthly evaporation water requirements, the total evaporation water requirement for the urban section of the Jian River is 93,700 cubic meters(93.7km³).

Table 5 Monthly Evaporation Water Requirement Calculation for the River Channel

Month	January	February	March	April	May	June
Average Precipitation (mm)	8.3	11	33.7	44.7	48.7	64
Average Evaporation (mm)	66.9	83.8	105.2	161.7	208.7	218.2
Evaporation Water Requirement (m³/s)	0.56	0.70	0.69	1.12	1.54	1.48
Month	July	August	September	October	November	December
Average Precipitation (mm)	141.1	105	64.8	41.1	28.6	4.1
Average Evaporation (mm)	186	157.8	126.9	101.8	81.1	72.5
Evaporation Water Requirement (m³/s)	0.43	0.51	0.60	0.58	0.50	0.66

Due to the lack of relevant data, the annual seepage loss of the river channel is estimated at 30%of the water body size when the water frequency is 50%over the past 20 years, which is approximately 43,000 cubic meters(4.3km³). Therefore, the total water requirement for evaporation and seepage in the urban section of the Jian River is 98,000 cubic meters(98km³).

5. Minimum sediment transport water requirement

To maintain the dynamic balance between sedimentation and erosion in a river, a certain amount of ecological water is required to match the sediment transport needs. This portion of water is referred to as the minimum sediment transport water requirement (or water-sediment balance water requirement). Under a given total sediment transport requirement, the sediment transport water volume depends on the sediment concentration in the river. The calculation formula is as follows:

$$W_s = S_t / k$$

In the formula:

W_s——Annual sediment transport water requirement, m³;

S_t——Average annual sediment transport, in kg;

k——Maximum monthly average sediment concentration, kg/m³.

The maximum average monthly sediment concentrations measured at Xin' an Station from 1962 to 2010 are shown in Table 6. According to Table 6, the maximum monthly average sediment concentration over the years is 82.70 kg/m³, and the average annual sediment transport is 419,100 tons. Based on these values, the minimum water requirement for sediment transport in the river channel is calculated to be 5,067,000 m³.

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Table 6: Maximum Monthly Average Sediment Concentrations and Sediment Transport Volumes at Xin' an Hydrological Station Over the Years

Statistical period	Maximum Monthly Average Sediment Concentration(kg/m³)												Annual Average Sediment Transport Volume (10,000 tons)
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
1962-2010	0.10	0.03	0.05	1.35	4.70	82.70	55.40	68.40	36.70	0.67	0.39	0.04	41.91

6. Conclusions

The factors influencing the ecological environment within a river channel are numerous and interact with each other in highly complex ways. Data on water temperature, water quality, flow conditions, sources of pollution, and the river's capacity to absorb pollutants are often scarce. In this study, we have estimated the ecological water requirements of the river channel from several aspects, including ecological base flow, water needed for water quality purification, water required for evaporation and seepage losses, and the minimum water required for sediment transport. Following the principle of non-redundant calculation, we have taken the maximum value among these requirements. As a result, we conclude that the ecological base flow for the urban section of the Jian River is 0.95 m³/s, with an annual water requirement of 30.1 million m³.

With the rapid development of the economy and society, human consumption, industrial and agricultural water use have surged dramatically. Hydropower resources have been developed fully, leading to increasingly prominent water supply and demand conflicts, as well as worsening water pollution and deteriorating water environments in natural rivers. Now, with the quantification of ecological water requirements, we can provide scientific basis for improving ecological environment quality, maintaining ecological balance, rationally allocating and utilizing water resources, increasing water use efficiency, and promoting the sustainable use of water resources.

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