

Estimation of Environmental Water Requirements via an Ecological Approach: A Case Study of Yongnian Wetland, Haihe Basin, China



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Abstract Due to natural change and special human destruction, the area of wetland is greatly decreasing. To recover the wetland ecological system has become an urgent task that must be faced. Water plays an important role in the course of wetland recovery. With Yongnian wetland as a case study, the ecological function method was used, based on structures and functions of the wetland ecological system, the ecological water requirement was divided into four parts: water requirement of wetland vegetation, water requirement of wetland soil, water requirement of wildlife habitats and water requirement of recharging ground water. According to the indexes that were presented in the paper, each part was classified to three grades, respectively. According to the formulas that were given in the paper, all kinds of ecological water requirement of Yongnian wetland were calculated; the results showed that the least ecological water requirement is $1.256 \times 10^8 \text{ m}^3$. The proper ecological water requirement is between $3.041 \times 10^8 \text{ m}^3$ and $4.301 \times 10^8 \text{ m}^3$, and the most ecological water requirement is $6.350 \times 10^8 \text{ m}^3$.

Keywords Wetland ecosystem health · Ecological water requirement
Haihe River basin · Yongnian wetland

1 Introduction

Wetlands, pivotal components of our environment and the cradles of biodiversity, cover approximately 5–8% of the world's land surface (7–10 million km^2) and must be preserved for their significant functions as natural habitats and global carbon cycling. A wetland has important resources, the unique ecosystem formed by the

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surface-land interaction, which plays a very important role in flood storage drought, regulating climate, controlling soil erosion, promoting silt-making and degrading environmental pollution, etc. [1]. Water is the dominant factor of a wetland's formation, development, succession, extinction and regeneration; and it is the key to the formation of the soil and the maintenance of biological species in the wetland ecosystem [2]. With the increasing tension of water resources, the research of ecological water demand has been paid close attention to by scholars. In this paper, the ecological function method [3] is used to study the ecological environment water demand of Yongnian Wetland in Hebei province.

2 Study Area

Ziya water system is located in the sea of Henan province, from the Taihang Mountains of Fuyang and from the northern slope of Wutai Mountain, Hutuo River. The catchment area of the Haihe River basin is 25%, and the population accounted for 16%. Yongnian wetland is located in the eastern part of Hanhan Yongnian County, north latitude $36^{\circ}40'60''$ – $36^{\circ}41'06''$, east of the $114^{\circ}41'15''$ – $114^{\circ}45'00''$, and the central lake is located in the ancient city; the south and east are adjacent to the Fuyang left dike; the west and the northern is a dike (Fig. 1). In recent years, the surface area of Yongnian wetland has been reduced seriously; its water resources and water environment are one of the most serious river systems in Haihe River basin, which is a typical epitome of the ecological environment of Haihe River basin.

3 Method

A wetland ecosystem is a complicated continuous system, and the existing calculation method lacks the cause and mechanism of wetland whole ecological evolution; therefore, the calculation results cannot be applied well to wetland protection and management. In the past two years, according to the theory of wetland eco-hydrological structure, the area of wetland central area is determined by hydrologic connection degree, and the research of wetland water demand analysis has made great progress. The research on ecological environmental water demand in foreign countries mainly concentrates on the river [4–6], which has less research on the wetland eco-environmental water demand. However, due to the lack of relevant data in most wetland research areas, the application range of hydrological connectivity has been limited. There is no specific quantitative analysis on how to carry out effective wetland water replenishment and how to rationally plan and design wetland water replenishment plan. There are two main methods to calculate the water demand of wetland ecological environment: wet-week method and Habitat method, which is costly and requires long-term observation and experiment.

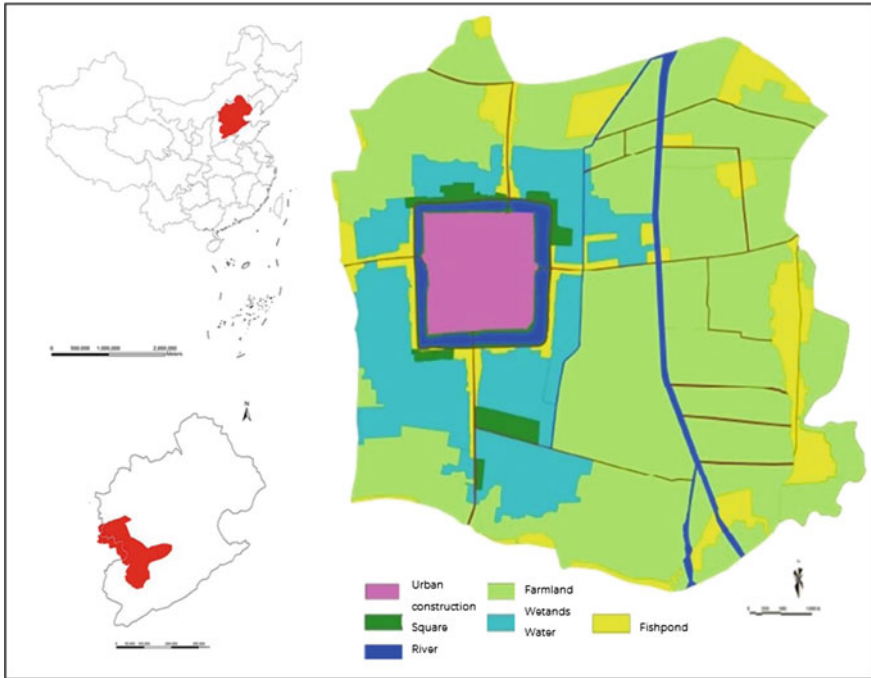


Fig. 1 Yongnian wetland and Ziya River basin

Domestic scholars have carried out much work in the theory and practical application of wetland eco-environmental water demand [7–13]; from a disciplinary point of view, there are hydrology and ecological methods. The former is mainly based on a series of data, through comparison, selection, modeling and so on; the latter is mainly according to the wetlands that are facing the key problems and ecological function value of water demand assessment. Because the research area is small and there is poor continuity of hydrology, the ecological function method is used to calculate.

Ecological water demand has a certain objective and maintains different ecological functions. To facilitate the study, the ecological water demand is divided into the largest, smallest and most suitable ecological water requirement. The maximum ecological water demand is the maximum amount of water that the system can withstand, and if it exceeds this threshold system, it may mutate; the minimum ecological water demand is the minimum amount of water needed for the ecosystem to maintain its own development; and the lower than the minimum water ecosystem will gradually shrink, degenerate or disappear. The most suitable ecological water requirement is the optimum water quantity for sustaining the development of the ecosystem, and the system is in the optimal state of development. According to the definition of wetland ecological water demand, the ecological water demand of Yongnian depression can be decomposed into: wetland

vegetation water demand, wetland soil water demand, biological habitat water requirement and recharge water requirement.

4 Calculation of Ecological Water Requirement of Yongnian Wetland

4.1 Water Requirement of Wetland Vegetation

The water requirement of wetland vegetation is the amount of water needed for vegetation to grow normally. Plant transpiration is much larger than that caused by plant population shadowing effect, and the vegetation water demand can be approximated as the water requirement of vegetation evaporation. The actual evaporation of vegetation was calculated by Penman formula. The water requirement of wetland vegetation can be regarded as the product of vegetation area and evaporation, and the formula is as follows:

$$Wp = a(t)ET \quad (1)$$

In the formula, WP is the wetland plant water requirement; a(t) is the wetland area; E is the vegetation coverage; T is the steam emission.

Referring to historical documents, the surface area of Yongnian WA in 1957 was 7 km²; The research institute uses remote sensing imagery Landsat TM7, TM4–5, MSS image data to download the Earth explorer image retrieval engine from the US Geological Survey (USGS). The time period is for years 1980, 1990, 2000, 2010, 2015; each year is 6-August data, which guaranteed the wetland is in the abundant water period. The interpretation of remote sensing image is carried out by Envi software. To improve the resolution of water and vegetation, 4, 3 and 2 bands of false color synthetic images were used, and the results of the Earth high-resolution image and field investigation were shown in Table 1. After on-the-spot investigation, the wild plant community in Yongnian WA wetland is the dominant species, which is more than 90%. Table 2 shows that the community has Moss, Lotus,

Table 1 The surface area of Yongnian wetland during 1957–2015

Year	Area/km ³
1957	15.7
1980	5.31
1990	3.57
2000	10.12
2005	8.68
2010	2.61
2015	3.86

Table 2 Water requirement of wetland vegetation

	Reed coverage/%	Annual steam emission/mm	Wetland area/km ²	Plant water requirement/ million m ³
Min	40	900	15.7	565.2
Suitable	60–70	1400–1600	15.7	1313.8–1758.4
Max	>90	1900	15.7	2331.45

Calamus and so on. To calculate the water requirement, the level of water requirement is divided into reed coverage degree.

4.2 Wetland Soil Water Demand

At present, the wetland soil water demand has not been clearly defined [14]; in the author’s case, that is the wetland ecosystem corresponding to the reserves. In the calculation, the soil moisture content is approximate, so the soil is special. And the two large water constants often appear in the calculation. First, the field holding water, indicating that if the water level is relatively deep, the soil layer can maintain the maximum water content. Because of the different characteristics of chemistry and physics, there are different water demands in all kinds of wetland soils. Combined with the requirement, the calculation can be completed by saturation and field water-holding capacity, which is the concrete formula as follows:

$$Qt = \alpha HtAt \tag{2}$$

The above formulas correspond to the water requirement, area, thickness, saturation, or volume water content of the wetland soil.

The soil moisture content test and wetland soil investigation in Time Domain Reflector (TDR) were carried out in August 2016, and the soil types involved in the region included peat soil, meadow and humus soil. Topsoil, grass-roots layer, is the thickness of about 10 cm. The soil layer of humus is 30 cm deep, and the peat layer is about 20 cm thick. The peat soil grass layer and peat layer thickness are 20, 40 cm, respectively. Because the peat soil has extremely strong water absorption, there exists the perennial stagnant water in which the soil is more saturated. Combined with the proportion of all kinds of soil and water characteristics, with saturation, field water-holding capacity is a concrete basis, according to the peat Swamp soil standards; the level of water requirements is delineated. The results are given in Table 3.

Table 3 Water requirement of wetland soil

Type of water holding	Volume moisture/%	Soil thickness/cm	Wetland area/km ²	Soil water demand/million m ³
Water-holding capacity in the field	30	30	15.7	141.3
Saturated water-holding capacity	50–60	30	15.7	235.5–282.6
Capacity for saturated water storage	>80	30	15.7	376.8

4.3 Biological Habitats

Birds, fish and other breeding habitats are wetland habitat water requirements as the basic water demand. The wetland system is composed of swamp vegetation and water surface, which can provide habitats for waterfowl, and can determine how the species richness is affected by the ratio of surface water and swamp vegetation area to a large extent [15]. Therefore, in general, in the calculation of this water demand, according to the water depth of the habitat, the proportion of the surface area to the level of water requirements can be divided and calculated; the specific formula is as follows:

$$Wq = A(t)CH(t) \quad (3)$$

In the formula, Wq is a biological habitat water requirement; C is the flooded area as a percentage of the total area; and $H(t)$ is water depth.

In recent years, due to the reduction of water area in sediment deposition, the wetland storage is often not more than 20 million m³, which is a large exposed land. Grain planting activity appeared in the periphery of the WA Lake, and the number and species of fishes decreased significantly. In the light of the 1983–1986 related survey, the natural fishing volume continues to decrease. Residents built about a hundred acres of aquarium, more for catfish, grass carp and other aquaculture; therefore, production has improved. In the continuous development of artificial aquaculture, fishery production has been increasing continuously. As a result of the local more pollution-resistant fish and waterfowl for minimum water requirement, the survival of waterfowl space can be ensured, in which the water flooded area accounted for the minimum value of 25%; and for the appropriate water index set, normal living space to fish, waterfowl can be provided. For the maximum water demand index, even if the optimal survival of fish meets the needs of water depth, Chen et al. [16] and other scholars give the results of the study, and the ideal depth is 2 m. The results of water requirement for biological habitat are given in Table 4.

Table 4 Water requirement of wildlife habitats

	Flooded area/%	Depth/m	Wetland area/km ²	Water requirement of wildlife habitats/million m ³
Min	25	0.5	15.7	196.25
Suitable	50–60	1.0–1.5	15.7	785–1413
Max	>80	2	15.7	2512

4.4 Water Requirement for Recharge Groundwater

Generally, combined with the leakage pathway, the wetland recharge groundwater can be completed because the wetland itself is related and more complex. The calculation makes the assumption that the recharge of groundwater is only partially involved in the water surface of the wetlands; and that if the swamp is not water-free, it only needs to be maintained for its own requirements, as follows:

$$Wq = kIAT \tag{4}$$

In the formula, *Wq* is the recharge water requirement; *k* is the permeability coefficient; *I* is hydraulic gradient; and *A* is the seepage section area, which is the calculation period length.

In 1985–2015, the monthly precipitation data of Lotus Estuary Hydrologic station were selected and analyzed; the precipitation appeared in May–October reached 438.2 mm, about 90% of the year. The replenishment time is calculated according to 180 days. In combination with the local soil type, the number of osmotic systems is determined, i.e. 0.005 m/d. Table 5 shows the result of water requirement of recharging groundwater in Yongnian wetland.

Table 5 Water requirement of recharging groundwater

	Flooded area/%	Permeability coefficient/(m d ⁻¹)	Wetland area/km ²	Replenishment time/d	Recharge groundwater requirement/million m ³
Min	25	0.005	15.7	180	353.3
Suitable	50–60	0.005	15.7	180	706.5–847.8
Max	>80	0.005	15.7	180	1130.4

Table 6 Wetland ecological water requirement

	Min/million m ³	Suitable/million m ³	Max/million m ³
Plant water requirement	565.2	1313.8–1758.4	2331.45
Soil water requirement	141.3	235.5–282.6	376.8
Water requirement for biological habitats	196.25	785–1413	2512
Water requirement for recharge groundwater	353.25	706.5–847.8	1130.4
Total	1256	3040.8–4301.8	6350.45

5 Results

After calculating the water demand (Table 6), it is found that the local ecological water demand is minimum, maximum and suitable values of 1256 million m³, 6350.45 million m³, 3040.8–4301.8 million m³.

5.1 Analysis on the Rationality of Maximum Value of Wetland Ecological Water Demand

In the Ziya Basin, Yongnian wetland belongs to one of the flood detention areas with design area of 16 km², and a lag of flood up to 54 million m³. According to the definition of maximum water requirement, it can be found that when the amount of water is exceeded, there will be floods and the calculation of the maximum ecological water demand is more scientific.

5.2 Analysis of the Proportions of Each Type

According to the different types of water requirement, the most important proportion is the water demand of plants, which is 45.86%, 42.75%–45.65% and 41.61%, respectively, in the minimum, the suitable and the maximum water requirement. With the level of increase, the proportion continued to decrease. The corresponding proportion of wetland soil water requirement is 11.25, 7.7–6.6 and 5.9%. With the level of increase, the proportion continued to decrease. The corresponding proportion of water demand for habitats is 15.6, 25.8–32.8 and 39.6%. With the level of increase, the proportion continues to increase. Groundwater recharge supplies corresponding to 28.1, 23.2–19.7 and 17.8%. The ratio continues to decrease as the level increases.

It can be found that the water demand in this area is mainly the evapotranspiration of vegetation, and the increase of water quantity will be more beneficial to the conservation of habitats.

5.3 Countermeasures for Ecological Protection of Yongnian Wetland

To protect the wetland ecological environment, water problems should be solved, and ecological water supplement work should be carried out. According to the local amount of water, for the problems faced, the corresponding seasonal characteristics and the implementation of concrete measures include the following:

- (1) This area uses Fuyang River as the main source of water and provides protection for urban and factory water supply. To ensure the ecological water replenishment, it is necessary to improve water efficiency and ensure the downstream ecological water.
- (2) Local government should unify the management and dispatching of water resources so that the utilization efficiency of water resources can be improved and the water environment can be improved so as to achieve the purpose of sustainable utilization. In the meantime, water conservancy projects should be dispatched reasonably and gradually transformed from open management to closed ones. Through the use of engineering measures, local water resources should be optimally allocated.

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