Eco-environmental water requirement for wetlands in Huang-Huai-Hai Area, China*

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Abstract Based on the related literature and the analysis of the relationship between wetland ecosystem and hydroperiod, the estimating and classifying methods of eco-environmental water requirement for wetlands are established. The data collected from Huang-Huai-Hai Area are from the electronic map (1:250000) of China National Topographical Database of 1997 and the historical statistics since the 1980s. The results indicate that the minimum eco-environmental water requirement for wetlands is 16.98×10^9 m^3 and the optimal one is 38.38×10^9 m^3 in the studied area. For the five wetland nature reserves covered in the area, the values are 1.47×10^9 m^3 and 3.31×10^9 m^3 respectively. The comparisons of the mentioned minimum water requirement with the status water use, which is 17.05×10^9 m^3 for wetland ecosystem (1997 as the status year), suggest that the water use has not met the minimum eco-environmental water requirement in the Haihe and Huanghe Basins of the studied area. However, the status water use guarantees and exceeds the minimum eco-environmental water requirement in the Shandong Peninsula and the Huaihe Basin. Based on the eco-environmental programming and water resource planning of the studied area, the study establishes the water requirement of the year of 2010, 2030, 2050, when the eco-environmental water requirement for wetlands is 18.30×10^9 m^3, 21.64×10^9 m^3 and 26.76×10^9 m^3, respectively.

Keywords: **eco-environmental water requirement, wetlands, Huang-Huai-Hai Area.**

Eco-environmental water requirement for wetlands is a newly integrated concept, which refers to the water regime needed to maintain wetland growing processes, and to protect biodiversity and to sustain human activities and life, as well as to improve environmental quality[1]. However, the eco-environmental water includes both surface water and groundwater, like the water regimes of wetlands, lakes and reservoirs, and river base flows, which are used to keep, build and improve environmental conditions. Moreover, the concept of eco-environmental water can be extended when considering vegetation evapotranspiration. However, soil water content, as a special element in the eco-environmental water, must be especially focused on. Though, on yearly average, its variety rate means nothing, soil water content each year can be distinguished from that of other years so as to sustain ecosystem processes. So soil moisture as an essential element of eco-environmental water component is considered in this paper.

Back to the late 1960s and the early 1970s, people began to assess and plan the famous Brahmaputra River Basin between India and Bengal (1960), Indian River Basin in Pakistan(1968) and the Nile River Works in Egypt(1972). The United States adjusted the objects of basin development and management in the 1980s, when the study on the eco-environmental water requirement was in the stage based on the systems analysis. However, the concept of ecological and environmental water requirement was not definitely stated then. It was not until the 1990s that the research on the relativity between water resources and eco-environment was formally in the limelight.

The concept of the basic ecological water requirement was put forward by Gleick[2], which is for providing a part of available water with certain quantity and quality to the natural environment, and changing the ecosystem process and protecting species diversity and ecological integrity[3]. Falkenmark distinguished the green water from water resources, and aroused human beings to pay attention to water allocation for ecosystem. The main content is that water supply should meet the requirement not only for human itself but also for ecosystem[1)]. Raskin et al. also suggested

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1) Falkenmark, M. Coping with water scarcity under rapid population growth. Conference of SADC Ministers, Pretoria, 1995, 23~24.

the sustainable water use should assure adequate water to protect rivers, lakes and wetland ecosystems[4], and the rivers and lakes for the opportunities of human recreation, navigation and hydraulic use must be kept at the minimum flows. Whipple et al. considered that the existing planning and management of water resources should take environmental needs and regulation into account[5], as the demand increasing for river transportation, hydroelectric, urban, industrial and agricultural usage, and in-stream environment maintenance. After analyzing the primary structure and function of all types of ecosystems, and the relationship between plants and hydrological processes (dryland, forest, river, lake, freshwater wetland), Baird et al. provided evidence for the vital role of water in protecting and restoring natural ecosystem[6].

In China, the study on ecological water was firstly carried out in Northwest China[7~10], then Li et al. discussed the environmental and ecological water consumption of the river system in the Haihe-Luanhe Basin[11], in which the basic water consumption for rivers, water consumption for sediments and salt transportation, water consumption for lakes evaporation were all considered. Some experts estimated the lowest ecological water requirement for whole China is $80\times10^9\ m^3\sim100\times10^9\ m^3$, which is to be used to protect and restore the natural vegetations and eco-environment of the upstream of inland, to construct the forest and grassland used by water-soil maintenance and others, to support the basis flows for the balance between water and sand and the eco-environment of wetlands, and to recharge groundwater[12,13]. Wang et al. discussed the conception of environmental water demand for instream based on water pollution, and taking the Weihe River, a branch of the Yellow River, as a case study, the results indicated that the lowest environmental water demand of Weihe River is $1.98\times10^9\ m^3$ per year, which accounts for 12.9% of the run off[14,15].

The studied area, Huang-Huai-Hai Area in North China, is located at 32°00′~40°30′N, 113°E to the eastern shoreline with an area of 413000 km^2 (Fig. 1), which consists of the Huang-Huai-Hai

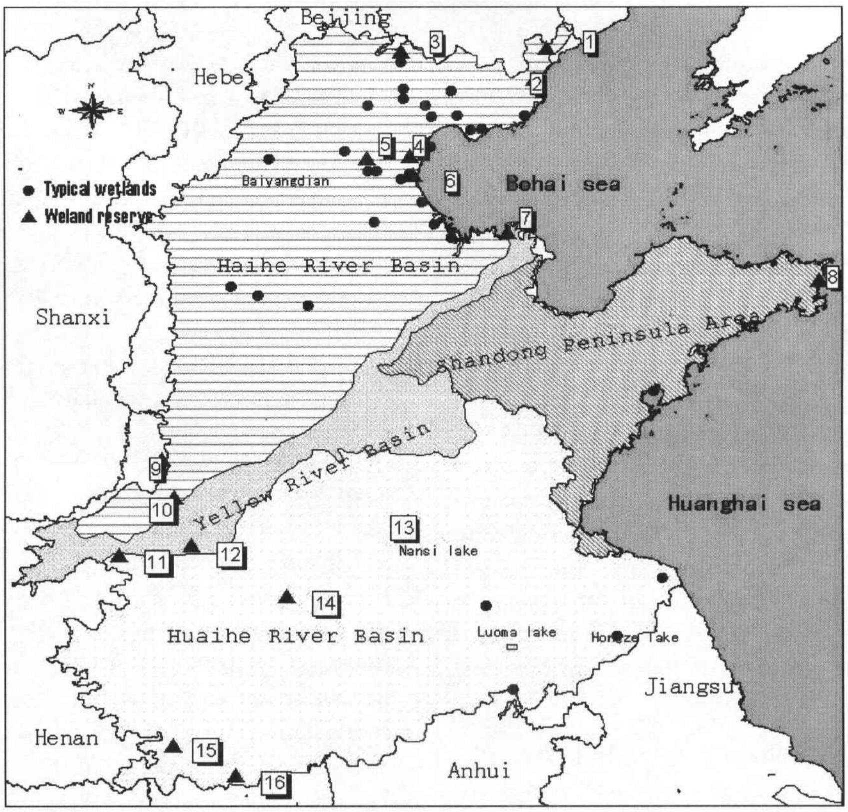

Fig. 1. Location and wetland distribution in the Huang-Huai-Hai Area. 1, Beidaihe waterfowls reserve, Hebei; 2, Golden coast reserve, Changli, Hebei; 3, Yuqiao water sources of reservoir, Tianjin; 4, Donglihu Lake reserve, Tianjin; 5, Tuanpo reserve, Tianjin; 6, Ancient coastal and wetland reserve, Tianjin; 7, Yellow River Delta reserve, Shandong; 8, Rongcheng reserve, Shandong; 9, Qihe reserve, Hebi, Henan; 10, Northern Old Course Yellow River reserve, Henan; 11, Huayuankou reserve, Zhengzhou, Henan; 12, Liuyuankou reserve, Kaifeng, Henan; 13, Nansihu Lake reserve, Shandong; 14, Old Course Yellow River reserve, Shangqiu, Henan; 15, Suyahu Lake reserve, Runan, Henan; 16, Huaibin and Huainan wetland reserve, Henan.

Plain and the Shandong Peninsula Region, including the middle-lower reaches of the Hai-Luanhe River, Yellow River, Huaihe River and Shandong Peninsula Region. During the last 30 years, the eco-environmental conditions of wetlands, for example, wetland areas and biodiversity, have degraded and decreased rapidly in the site. The South to North Water Transfer Project in China provides an opportunity to mitigate water scarcity and to set up sound water requirement for eco-environment in the studied area. It is an imperative issue to allocate enough water for eco-environment and to satisfy its domestic water demand as well[16]. This paper aims to develop quantitative analysis method based on a case study on wetlands in the Huang-Huai-Hai Area, to analyze the difference between water use status and the minimum eco-environmental water requirement, and to predict the demands and changes in the coming 50 years.

1 Study methods

In this paper the data are collected from the electronic map (1 : 250000) of China National Topographical Database of 1997 and the historical statistics since the 1980s. Wetlands, which are defined by Three-parameter (vegetation, soil and hydrology) method, include the key nature reserves, typical lakes, lowland marshes and swamps and plain reservoirs. Where their areas are larger than 10 km^2 respectively[17,18] (Tables 1 and 2). The nature reserves that overlap the typical wetlands are considered as typical wetlands in this study.

According to the holistic ecosystem approach, this paper firstly divides the structural and functional components into different classifications by the ecological characteristics and the difference in water requirement, then 5 levels, maximum, excellent, better, middle and minimum values are determined (Table 3).

Table 1. The nature wetland reserves in Huang-Huai-Hai Area

Reserve	District	Area(km^2)	Conservation objective	Level
Tuanpo, Tianjin	Jinghai County	60.00	Birds, wildlife, wetland ecosystem	Municipal
Donglihu Lake, Tianjin	Dongli District	22.00	Aquatic life	County
Ancient coasts and wetlands, Tianjin	Ninghe and Dagang County, Jinnan District	211.80	Conch dike, oyster beach, ancient vestige and coastal wetland ecosystem	National
Ancient coasts and wetlands, Tianjin	Nanjiao District	277.30	Oceanic and coastal ecosystem	National
Yuqiao water sources of reservoirs, Tianjin	Jixian County	235.57	Inland wetlands and water body ecosystem	Provincial
Beidaihe waterfowls, Hebei	Beidaihe District	11.00	Waterfowl	Provincial
Golden coast, Changli, Hebei	Changli County	300.00	Oceanic and coastal ecosystem	National
Changdao, Shandong	Changdao County	53.00	Waterfowl	National
Yellow River Delta, Shandong	Dongying City	1530.00	Original wetland ecosystem and rare and endangered birds	National
Nansihu Lake, Shandong	Weishan County	1200.00	Ducks and habitats	Municipal
Rongcheng, Shandong	Rongcheng City	67.00	Waterfowl and habitats	Municipal
Northern old course Yellow River, Henan	Xinxiang City	247.80	Wildlife, waterfowl and wetlands ecosystem	National
Liuyuankou, Kaifeng, Henan	Kaifeng City, Kaifeng and Lankao County	200.00	Rare waterfowl	Provincial

Table 2. The basic characters of typical wetlands in Huang-Huai-Hai Area

Wetland	Areas (km^2)	Location	Wetland	Area (km^2)	Location
Bamencheng reservior	25.60	Baodi County, Tianjing City	Caozhuangzi marshes	14.62	Laoting County, Hebei Province
Erwangzhuang reservior	32.39	Baodi County, Tianjing City	Daqinghe marshes	116.32	The boundary of Wen' an and Bazhou County, Hebei Province
Dahuangpu marshes	47.78	Wuqing County, Tianjin City	Baiyangdian lakes	366.00	Baoding City, Hebei Province
Qilihai marshes	86.40	Ninghe County, Tianjin City	Nandagang reservior	160.41	Huanghua County, Hebei Province
Dajiazhuang marshes	19.20	Ninghe County, Tianjin City	Yangchen marshes	53.26	Haixing County, Hebei Province
Beitang reservior	96.00	Tanggu Suburb, Tianjin City	Enxianwa lowlands	106.75	Gucheng County, Hebei Province

To be continued

Continued

Wetland	Areas (km^2)	Location	Wetland	Area (km^2)	Location
Tuanpowa reservior	60.00	Jinghai County, Tianjin City	Wudi shore	243.00	Wudi County, Shandong Province
Beidagang reservior	251.00	Dagang Suburb, Tianjin city	Laizhou bay shore	750.00	Laizhou City, Shandong Province
Mapengkou marshes	54.40	Dagang Suburb, Tianjin City	Daguhe river estuary	23.00	Jiaozhou City, Shandong Province
Donglihu lakes	15.80	Dongli Suburb, Tianjin City	Dongping lakes	627.00	The boundary of Dongping and Liangshan County, Shandong Province
Dongdian marshes	86.80	Jinghai County, Tianjin City	Nansihu lakes	1408.43	The boundary of Jining and Zaozhuang County, Shandong Province
Dalangdian marshes	61.00	Qixian County, Tianjin City	Rongcheng swamp	45.00	Rongcheng City, Shandong Province
Qianqinwa lakes	49.00	Cangzhou City, Hebei Province	Guanyun marshes	15.20	Guanyun County, Jiangsu Province
Ninjingpo lakes	62.59	Jizhou City, Hebei Province	Binhai marshes	56.63	Binhai County, Jiangsu Province
Qingdianwa lowlands	156.56	Ningjin County, Hebei Province	Funin marshes	24.17	Funing County, Jiangsu Province
Youhulupo lowlands	53.69	The Boundary of Fengrun and Fengnan County, Hebei Province	Hongzehu lakes	1576.90	Huaiying County, Jiangsu Province
Douhe swamp	115.15	Fengnan County, Hebei Province	Luomahu lakes	297.21	The boundary of Suqian and Xinyi County, Jiangsu Province
Donghuangtuo swamp	27.89	The boundary of Tanghai and Luannan County, Hebei Province	Suyahu lakes	180.00	Runan County, Henan Province
Suhe swamp	51.20	The boundary of Tanghai and Luannan County, Hebei Province	Total	7416.35	

Table 3. The level classification and their foundation of the eco-environmental water requirement for wetlands

Classification	Indicator	Minimum	Middle	Better	Excellent	Maximum
Wetland vegetation	Reed community levels	IV	III	II	I	I
	Evapotranspiration (mm)[a)]	900.00	1100.00	1300.00	1500.00	1900.00
Wetland soil	Holding water capacity(%)[b)]	25.00	35.00	45.00	55.00	80.00
Wildlife habitats	Area percentage of inundation (%)[c)]	12.50	20.00	35.00	55.00	100.00
	Water depth (m)[d)]	0.40	0.60	0.85	1.25	>2.00
Groundwater recharge	Area percentage of inundation (%)[e)]	12.50	20.00	35.00	55.00	80.00
Avoiding saltwater intrusion	Rising extend[f)]	0.75	1.00	1.75	2.25	>2.50
Avoiding shoreline erosion	Ratio of eroding and silting[g)]	1:4	1:3	1:2	1:1	1:1
Wastewater purifying	National standard levels[h)]	V	IV	III	II, I	I
Dissolving and flushing salt	Salt capacity expected(%)[i)]	0.60	0.50	0.30	0.15	<0.10

a) Potential evapotranspiration, the levels are classified by reed community character and their growth conditions; b) based on the range of field water-holding and saturated water content; c~d) it is possible that the wetlands ecosystem composed of water body and marsh vegetations can provide the optimal habitat environment, thus, the relative ratio between water body and marsh vegetation may be the most vital factor to determine species abundance. According to the above analysis and conclusion, the levels of water requirement for wildlife habitats are classified by the water depth and the percentage of water body area in wetlands; e) the levels are divided according to the percentage of the definite and enough water bodies in wetlands; f) the levels of water requirement for refilling filler areas are divided by the characteristics of the depressed area, overpicking amounts of groundwater and rising extent; g) the levels are classified by analyzing the difference of water amount into the sea from rivers at certain eroding and silting ratios in various years; h) the levels are based on the standard of water quality that are divided by five functional classifications of surface water correspondingly. The corresponding admission concentration of NH_3-N, COD_{cr} and BOD_5 abide by the latest standard of environmental quality of surface water in China. The discharging concentration of pollutant obeys the comprehensive emission standard of sewage. The sewage into functional water bodies of class IV and class V acts as National Class II standard; i) the expected salt capacity is defined as the classification basic for flushing and dissolving salt. The original salt content of surface soil is assumed as 1.5%, the depth of deviating salt planned is 80 cm, the salt content of surface soil is planned to reduce from 1.5% to the expected values within 20 d.

The maximum water requirement is the largest carrying capacity for wetlands, and wetland ecosystem may generate mutation if it exceeds the maximum value; the excellent water requirement can keep the optimum operating point of ecosystem; the minimum water requirement is the lowest value that ecosystem must maintain to develop itself, below which wetland ecosystem would rapidly degrade and disappear; the better and middle water requirements among the above three classes are considered to be transitional classes, which may develop along the different directions under different management ways and environmental conditions, so the two types also must be especially paid attention to and monitored.

Table 4 presents the equations estimating for eco-environmental water requirements for wetlands.

Table 4. Equations of eco-environmental water requirement for wetlands

Classification	Equation	Related expression
Wetland vegetation	$dW_p/dt = A(t)ET_m(t)$	W_p is the water requirement of vegetation, $A(t)$ the area of wetland vegetation, ET_m evapotranspiration, t unit year.
Wetland soil	$Qt = \alpha\gamma HtAt$	Qt is water requirement of soil, α percentage of field capacity or saturation water content, based on soil classes, γ soil apparent density, Ht soil thickness, adopting 1.5 m, At soil area.
Wildlife habitats	$dW_q/dt = A(t)\%H(t)$	W_q is water requirement of wildlife habitat, $A(t)$ wetland area, % the percentage of water body area, $H(t)$ water depth, t time(year).
Groundwater recharge	$W_b = kIAT$	W_b is the amount of recharge, k penetration coefficient, adopting 0.005 m/d, I hydraulic gradient, A the area of seepage section, T the period calculated, adopting 180 d.
Avoiding saltwater intrusion	$Q_f = \alpha A_f H_f$	Q_f is water requirement, α feedwater degree, adopting 0.05, A_f the area of groundwater filler in coastal region, H_f rising range of water level.
Avoiding shoreline erosion	$W = Q_y/C_n$	W is water requirement, Q_y annual filled amount of sand, C_n capacity of discharging, experience data, adopting 500×10^6 m^3(sand sediment)/100×10^6 m^3(water requirement).
Wastewater purifying	$dWj/dt = pQ_d(t) + \beta Q_f(t)$	Wj is water requirement, t the temporal period, $Q_d(t)$ the acceptable sewage emission from point sources, $Q_f(t)$ the sewage into wetland from no-point sources, p, β are the diluted multiple correspondingly from point and no-point sources, the calculating diluted multiple relies on the concentration ratio of expected or acceptable emission and China National Standards.
Dissolving and flushing salt	$Wy = AvnT$	Wy is the water requirement, A the salt soil area flushed, v the velocity of flow of penetration from flushing water, v value is related to the original concentration of salt contained, expected salt concentration, the depth of deviating salt planned, saturated water content of soil, the dispersion coefficient of hydraulic, the estimating equation refers to the Laplace transform from Zhanyu Zhang et al.[19]. n is the soil porosity, T the flushing period planned.

2 Results and discussion

The results of eco-environmental water requirement of five key nature reserves and the typical wetlands are displayed in Tables 5, 6 and 7, in which the characters of water usage status and supplementary water for annual consumption are also presented. The minimum eco-environmental water requirement for wetlands in the Huang-Huai-Hai Area, based on the integration (deducting from overlap parts) of water requirements from that of typical wetlands and wetland nature reserves in the studied area, is about 16.98×10^9 m^3.

Table 5. Eco-environmental water requirement for 5 wetland nature reserves ($\times10^6$ m^3)

Title	Minimum	Middle	Better	Excellent	Maximum
Golden coast, Changli, Hebei	25.00	32.00	45.00	60.10	90.00
Annual supply water required[a)]	14.00	20.50	31.00	38.50	48.00
Northern Old Yellow River channel, Henan	54.80	73.90	92.00	127.50	251.00
Annual supply water required	34.10	43.50	54.80	67.50	127.00
Yellow River Delta, Shandong	1231.00	1645.00	2198.00	2800.00	4970.00
Annual supply water required	784.50	996.00	1294.00	1610.00	2380.00
Ancient coast and wetlands, Tianjin	111.30	148.00	195.00	249.00	496.00
Annual supply water required	68.30	87.30	110.00	136.00	251.00
Liuyuankou, Kaifeng, Henan	35.70	47.10	62.50	80.00	118.00
Annual supply water required	22.20	28.00	35.10	44.00	61.00
Total	1472.00	1965.00	2597.00	3311.00	5926.00
Total of annual supply water required	940.00	1196.00	1522.00	1900.00	2870.00

a) Annual supply water required from vegetation water consumption, recharge groundwater and estuary water demands for its existing eco-environmental maintenance.

Table 6. Eco-environmental water requirement for the typical wetlands ($\times10^9$ m^3)

Class	Minimum	Middle	Better	Excellent	Maximum
Wetland vegetation	6.74	8.24	9.74	11.23	14.23
Wetland soil	3.71	5.19	6.67	8.15	11.86
Wildlife habitats	0.93	1.48	2.60	4.07	14.83
Recharging groundwater	0.83	1.33	2.33	3.67	6.67
Estuary environment[a)]	0.06	0.08	0.15	0.20	>0.20
Recreation	0.93	1.48	2.60	4.07	14.83
Dissolving and flushing salt[b)]	0.29	0.35	0.42	0.47	>0.50
Avoiding saltwater intrusion and returning groundwater[c)]	0.32	0.53	0.74	0.95	>1.06
Purifying pollutant	2.80	3.83	5.40	6.30	6.30
Total(average)	15.6	21.04	28.05	35.07	55.66
Annual supply water required	8.30	10.23	12.59	15.57	30.12

a) Only estuaries of Haihe and Huanghe considered; b) the area of salt soil estimated is 1333.8 km^2; c) the filler area considered is 8471 km^2.

Table 7. The status of the eco-environmental water usage of wetlands ($\times10^6$ m^3)

Golden coast, Changli, Hebei	Northern Old Yellow River channel, Henan	Yellow River Delta, Shandong	Ancient coast and wetlands, Tianjin	Liuyuankou, Kaifeng, Henan	Typical wetlands	Total
25.00	63.00	984.00	143.00	46.00	15790.00	17050.00

The status year is 1997, those estimated include wetland vegetation, soil, wildlife habitat, recharge and estuary.

It must be emphasized that the purifying effect of wetlands for COD is only 20 t/km^2 in literature[20,21]. There is about 7416.35 km^2 of typical wetlands in the Huang-Huai-Hai Area (Table 2), so it can only treat 1.50×10^6 m^3 of sewage. But the amount of sewage emission was 14.88×10^9 t in 1999 in the studied area, and the sewage that wetlands received is assumed to be 10% of the amount (based on the wetland area percentage covering the area of the river continuum, as well as the status of sewage as irrigation use). However, the existing wetlands cannot attain to self-purification, as a result, the contaminants must be diluted by a certain amount of water to protect wetland habitats and biodiversity.

According to the basin characteristics and wetland conditions in the Huang-Huai-Hai Area, the wetland area of the Haihe River Basin accounts for 29.25% of the studied area, the Huanghe River Basin is 13.75%, the Shandong Peninsula Region is 9%, and the Huaihe Basin is 48%. The water requirements for wetlands of the three Basins and the Peninsula Region of the studied region are estimated and listed in Table 8 (regardless of the above 5 nature reserves).

Table 8. Eco-environment water requirement for wetland in three Basins and Peninsula Region in the studied area ($\times 10^9$ m^3)

Basin	Minimum	Middle	Better	Excellent	Maximum
Haihe Basin	4.55	6.15	8.19	10.26	15.64
Huanghe Basin	2.14	2.89	3.85	4.82	7.35
Shandong Peninsula	1.40	1.89	2.52	3.16	4.81
Huaihe Basin	7.47	10.11	13.44	16.83	25.66

As mentioned above it is easy to have a conclusion that the status eco-environmental water consumption of wetland nature reserves, which need 0.94×10^9 m^3 of water supplying annually to maintain the status wetland environment, has reached the minimum water requirement except for the Yellow River Delta wetland nature reserve, that is to say, the basic condition of maintaining and improving wetland environments is perfect, and setting up wetland nature reserve is an available means to protect wetlands and its biodiversity. For the Yellow River Delta wetland nature reserve where the status water use cannot attain to the minimum water requirement, and the major conflict between oil field development and ecological protection must be effectively dealt with in order to coordinate conservation and development, it is imperative to supply water for the Delta wetlands. The amount of status water use (15.79×10^9 m^3) in typical wetlands is slightly bigger than that of the minimum water requirement (15.60×10^9 m^3), that is to say, the general water use of typical wetlands has met the minimum water requirement in the Huang-Huai-Hai Area. However, because of the spatial distribution imbalance of water resources, the water use cannot attain to the minimum water requirement in the northern studied area but that of the southern studied area is contrary to it (Tables 7 and 8). The results also show that 8.30×10^9 m^3 of water supplying annually is needed to maintain the status wetland environment of Huang-Huai-Hai Area.

Based on the related programming and planning, the study establishes and develops the water requirement objectives in the near future, metaphase and at the specified future so that the predicted eco-environmental water requirement for wetlands will attain to different levels in different stages. At the same time, the priorities of eco-environmental water must be achieved in wetland nature reserves in which water requirement should obtain relatively high levels.

(i) In the near future (2010)

The decreasing trend of wetland caused by human activities will be controlled and mitigated[22]; the degraded wetlands of nature reserves will be restored; some small nature reserves will integrate and some new wetland reserves should be established.

The typical wetlands will attain to the minimum level of eco-environmental water requirement. At the same time, a 70% cutting rate of COD emission is expected by 2010 when water requirement can be reduced about 1.96×10^9 m^3. The above 5 nature reserves can reach the middle level of the eco-environmental water requirement. The newly planned reserves must meet the minimum eco-environmental water requirement (excluding reserves overlapping typical wetlands, Table 9).

Table 9. The eco-environmental water requirement for 4 newly planned reserves

Title	Minimum	Middle	Better	Excellent	Maximum
Huaibin and Huainan waterfowl reserve, Henan	0.28	0.38	0.50	0.65	1.46
Qihe wetland reserve, Hebi, Henan	0.28	0.38	0.50	0.65	1.46
Huayuankou waterfowl reserve, Zhengzhou, Henan	0.78	1.06	1.40	1.83	4.10
Old Course Yellow River reserve, Shangqiu, Henan	0.98	1.32	1.75	2.28	5.16
Total	2.32	3.14	4.15	5.41	12.20

(ii) Metaphase (2030)

Original wetland nature reserves will be restored and play definite roles in social, economic and ecological functions; a set of typical lowlands and marshes will be restored and other interrelated wetland nature reserves will be established.

The reserves built during the 2010s and typical wetlands can reach the middle level of eco-environmental water requirement, and diluted water by 2030 is not considered because of 100% cutting rate of COD emission. The five nature reserves can reach the better level of eco-environmental water requirement.

(iii) In the specified future (2050)

All kinds of typical lowlands, marshes and swamps greater than 10 km^2 will be restored successfully and some new wetland nature reserves will be set up; the natural wetlands and biodiversity will be protected efficiently.

The typical wetlands will attain to the better level of eco-environmental water requirement, and all wetland reserves should be near the excellent levels.

According to the above principles, the eco-environmental water requirement should be 18.30×10^9 m^3, 21.64×10^9 m^3, 26.76×10^9 m^3 by 2010, 2030, 2050 respectively. In addition, the status eco-environmental water use and water requirements for wetlands are estimated in three Basins and the Peninsula Region of the studied area in the coming 2010, 2030 and 2050 (Table 10).

Table 10. The status water use and prediction for eco-environmental water requirement of wetlands in three Basins and the Peninsula Region in the studied area ($\times10^9$ m^3)

Basin	Status water use	2010	2030	2050
Haihe Basin	2.52	4.00	5.19	6.80
Huanghe Basin	3.02	3.50	4.45	5.70
Shandong Peninsula	1.40	1.40	1.89	2.52
Huaihe Basin	10.11	9.40	10.11	11.74

Including wetland reserves.

Table 10 shows that the values of status eco-environmental water use of wetlands (2.52×10^9 m^3 and 3.02×10^9 m^3) are less than the minimum water requirements (4.68×10^9 m^3 and 3.46×10^9 m^3) in the Haihe Basin and the Huanghe Basin respectively. The two basins are planned to attain to the minimum water requirements in 2010, the tasks of providing water for the wetland ecosystems are imperative and hard in the Haihe Basin and Huanghe Basin. The status eco-environmental water use (1.40×10^9 m^3) and the minimum water requirement (1.40×10^9 m^3) for wetlands are balanceable to maintain ecosystem development in the Shandong Peninsula Region. However, it is easy to change in the different directions. The status eco-environmental water for wetlands (10.11×10^9 m^3) is much bigger than the minimum water requirement (7.47×10^9 m^3) in the Huaihe Basin, which shows that the wetlands of the Huaihe Basin have guaranteed the minimum eco-environmental water requirement, and can supply definite water for other surrounding wetlands by 2010.

3 Conclusions

(i) The total water use of typical wetlands has met the minimum water requirement in the Huang-Huai-Hai Area. However, because of the spatial distribution imbalance of water resources, the water use cannot attain to the minimum water requirement in the northern studied area but that of the southern studied area is contrary to it.

(ii) Setting up wetland nature reserves is an effective means to guarantee the eco-environmental water use and protect wetlands and their biodiversity.

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