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## ENVIRONMENTAL AND ECOLOGICAL WATER REQUIREMENTS OF A RIVER SYSTEM: A CASE STUDY OF THE HAIHE-LUANHE RIVER SYSTEM

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*ABSTRACT: In order to reduce the environmental and ecological problems induced by water resources management and use, this paper proposes a concept of environmental water requirement. It is defined as the minimum water amount to be consumed by the natural water bodies to conserve its environmental and ecological functions. Based on the definition, the methods for calculating the amount of environmental and ecological water requirement are determined. In the case study on Haihe-Luanhe river system, the water requirement is divided into three parts, i.e., the basic in-stream flow, water requirement for sediment transfer and water consumption by evaporation of the lakes or everglades. The results of the calculation show that the environmental and ecological water requirement in the river system is about  $124 \times 10^8$  m<sup>3</sup>, including  $57 \times 10^8$  m<sup>3</sup> for basic in-stream flow,  $63 \times 10^8$  m<sup>3</sup> for sediment transfer and  $4 \times 10^8$  m<sup>3</sup> for net evaporation loss of lakes. The total amount of environmental and ecological water requirement accounts for 54% of the amount of runoff ( $228 \times 10^8$  m<sup>3</sup>). However, it should be realized that the amount of environmental and ecological water requirement must be more than that we have calculated. According to this result, we consider that the rational utilization rate of the runoff in the river systems must not be more than 40%. Since the current utilization rate of the river system, which is over 80%, has been far beyond the limitation, the problems of environment and ecology are quite serious. It is imperative to control and adjust water development and utilization to eliminate the existing problems and to avoid the potential ecological or environmental crisis.*

*RESUMEN: Con el fin de reducir los problemas ambientales inducidos por la gestión y uso de los recursos hídricos, este trabajo propone el concepto de requisitos ambientales del agua. Se define como la mínima cantidad de agua que debe mantenerse en las masas naturales de agua para conservar sus funciones ecológicas. A partir de esta definición se establecen los métodos de cálculo de tales requisitos. En el caso del sistema del río Haihe-Luanhe, el requisito hidrológico se divide en tres partes: el flujo básico en el cauce, el agua necesaria para el transporte de sedimento y el agua consumida por evaporación en lagos y humedales. El resultado del*

*cálculo muestra que los requisitos ambientales de agua se estiman en  $124 \times 10^8$  m<sup>3</sup>, incluyendo  $57 \times 10^8$  m<sup>3</sup> como flujo de base,  $63 \times 10^8$  m<sup>3</sup> para el transporte de sedimento y  $4 \times 10^8$  m<sup>3</sup> para evaporación neta en lagos. Estas cifras representan el 54% de la cantidad total de escorrentía ( $228 \times 10^8$  m<sup>3</sup>). Sin embargo, sería deseable que la cantidad de agua ambiental fuera aún mayor que la calculada. De acuerdo con este resultado, consideramos que una tasa racional de utilización no debería ser mayor del 40%. Puesto que la tasa de utilización actual está por encima del 80%, los problemas ambientales son muy serios. Es imprescindible controlar y ajustar la gestión del agua para eliminar los problemas y evitar la potencial crisis ecológica.*

**Key-words:** Environmental and ecological water requirement, River systems; Haihe-Luanhe basins, China.

**Palabras clave:** Requisitos ambientales, Sistema fluvial, Cuenca del Haihe Luanhe, China.

## 1. Introduction

River system, to some extent, can be regarded as an independent eco-system, which includes river channels, lakes and the lands near the water bodies. In the engineering view, river system can be defined as the flooded area with a flood frequency of 1% (Boon, 1992; Petts, 1984). The major aspects of the river system are water quantity, water quality and aquatic species. The three aspects of the system have a close relation with each other. The river system has a lot of functions, of which in general, its ecological functions, environmental functions and resources property are the most important. From the perspective of the socio-economic development, the river system plays an important role for water supply, navigation, electricity generation and aquaculture, whereas the environmental functions of the river system may include climate adjustment, groundwater recharge, flood regulation, sediment and solute transfer, pollutant dilution and degradation. Moreover, the river system may be an attractive scenery for entertainment. As for the ecological functions, the water bodies, flooded area, everglade and estuary are the best location for aquatic species with a great diversity, since water and sediment carry out abundant nutrients. The aquatic species in the river system, on the one hand, are one of the important comestible sources for human beings; on the other, those species in the system may have an effect on pollutant degradation.

The dynamic ecological balance is the base for sustainable development of human civilization. To keep and protect the ecological balance and environmental sound of the river system, it must be regarded that the system is an organic integration in the process of water resources development and utilization. The economic, environmental and ecological aspects of the river system must all be taken into account. It is necessary to harmonise the relations among all the three aspects for sustainable development. Therefore water requirement for environment and ecology must be under full consideration and that part of water requirement must be set for use beforehand during the process of the integrated planning of the river systems.

However, in the aspect of water resources development and utilization in China, water requirement for environment and ecology has been ignored for decades of years, when attention was mainly paid to the agricultural, industrial and domestic water use. It is just because of this ignorance that water environment and aquatic eco-systems have been seriously devastated and the degradation of water bodies has been accelerated with the renewability of water resources seriously threatened, which has aggravated water resources crisis. As a result, the environment has become more fragile and hydrological disasters occur more frequently. Take the Haihe-Luanhe river system for instance, because of excessive water development and utilization, there is a great pressure on environmental and ecological protection and rehabilitation. Since there is not enough water in the natural water bodies to meet the environmental and ecological water demand in many places in the system, a series of environmental and ecological problems such as the shrinkage of river channel, the degradation of water quality etc., have occurred, and even some perennial rivers have become seasonal ones (Liu Changming & Wei Zhongyi, 1989; Yu Fenlang *et al.*, 1994; Fang Ziyun, 1993; Wu Kai and Xu Yuenxian, 1997).

## **2. Concept of environmental and ecological water requirement**

Environmental and ecological water requirement for river systems is a new concept proposed for environmental and ecological protection in the field of water resources development and utilization. It is of great importance for reasonable ecological rehabilitation and amendment. Nevertheless, a standard definition of this concept has not been adopted yet. According to the actual researches (Liu Changming, 1999; Jia Baoquan and Ci Longjun, 2000), to keep the structure and functions of the natural eco-system in a suitable situation, it is recognized that the water requirement may include the following aspects: (1) water consumed by the natural and planted vegetation in the river system; (2) water required by aquatic species; (3) water required for ecological balance in the estuary; (4) water for sediment transfer; (5) water for solute transfer; (6) water for dilution and decontamination; (7) water for suitable weather and entertainment; (8) water for evaporation; and (9) water for groundwater recharge.

However, in practice, the total amount of environmental and ecological water requirement is not the sum of water requirement in the above mentioned aspects. Since a certain amount of water resources may have various functions in different aspects at the same time, the amount of water requirement for the river system has to be calculated by careful analysis on their correlation. In addition, one important thing is that water for environment and ecology is not just a concern of quantity but also has a requirement on the temporal distribution. For instance, we can use the flood for sediment transfer. On the other hand, for protecting the primary functions of the river system such as decontamination and providing a suitable location for the aquatic species, a certain amount of water should be guaranteed at all seasons. For some rivers, there is a large amount of runoff flowing into the sea during the flood season while in the drought period the river channel may dry up. Regarding to such a circumstance, hydro-projects and other measures should be taken to adjust the natural hydrological situation of the rivers to meet their environmental and ecological needs.

With the comprehensive understanding of the concept of environmental and ecological water requirement, narrowly speaking, the water requirement can be defined as the minimum amount of water that should be kept or consumed by the natural water bodies for certain environmental and ecological functions rooted in the river system. According to the definition, three parts are decomposed in calculating the total amount of the water requirement, namely, (1) the basic in-stream flow, which is the minimum amount of water needed for protecting the most primary environmental and ecological function of the rivers; (2) water for sediment and solute transfer, which is part of water required to transfer sediment and salt in a certain situation to keep the dynamic balance of the river system; and (3) water consumed by lakes and everglades, which refers to water evaporation in the lakes and everglades in order to maintain their general function.

### 3. Calculation of environmental and ecological water requirement

#### 3.1. Basic in-stream flow

For perennial rivers, to protect the primary functions of a river system means that we must keep runoff of the rivers to a certain level at all seasons to avoid the occurrence of some disaster phenomena such as drying-up in the river channels. Thus, the basic in-stream flow is called to provide a suitable environment for the aquatic species and also to some extent it may bring benefits to sediment and solute transfer, groundwater recharge and decontamination. Considering all these factors, the basic in-stream flow ( $W_b$ ) can be calculated according to expression (1):

$$W_b = \frac{T}{n} \min_i(Q_{ij}) \times 10^{-8} \quad (1)$$

where  $Q_{ij}$  is the mean daily runoff of the  $j$ th month in the  $i$ th year,  $T$  is a constant with a value of  $31.536 \times 10^6$ s, and  $n$  is the number of the years under consideration. As for the Haihe-Luanhe river system, the impact of human activities could be ignored as it is rather weak before the 1970s, so the hydrological data observed during the period is used.

According to expression (1), the total amount of the basic in-stream flow of the Haihe river system and the Luanhe river system is about  $48 \times 10^8 \text{ m}^3$  and  $9 \times 10^8 \text{ m}^3$  respectively whereas that of the Haihe-Luanhe river system is  $57 \times 10^8 \text{ m}^3$ . Table 1 gives the results in detail.

#### 3.2. Water requirement for sediment transfer

According to the sediment features at different sections of the river, the channel can be divided into three parts. They are i) the eroding segment in the upper reaches where the sediment is produced, ii) sediment transfer segment in the middle reaches and iii) the silting segment in the lower reaches of the river. For a river concerned, the balance between eroding and silting is very important in its evolution process. To keep the dynamic balance of the river, water for sediment transfer is required.

In the light of a certain amount of sediment transfer, the amount of water requirement directly depends on the sediment content of the flow. However, the sediment content may change with the amount of the sediment produced and that of runoff. Even more, the other features of the river may have an effect on the sediment content.

*Table 1. Basic in-stream flow for major rivers of Haihe-Luanhe river systems*

<i>Rivers</i>	<i>Stations</i>	<i>Mean minimum monthly runoff/m<sup>3</sup>/s</i>	<i>Basic in-stream flow/10<sup>8</sup>m<sup>3</sup></i>	<i>Periods</i>
Luanhe	Luanxian	29.6	9.335	1929-1970
Jiyunhe	Jiuwangzhuang	8.39	2.646	1930-1970
Chaobaihe	Suzhuang	11.0	3.478	1920-1958
Yongdinghe	Guanting	13.0	4.100	1956-1970
Daqinghe	_total_	19.27	6.077	
Ziyahe	Xianxian	60.9	19.205	1918-1967
Fuyanghe	Hengshui	2.18	0.687	1920-1970
Hutuohe	Huangbizhuang	8.72	2.750	1934-1960
Ziyahe	Nanzhaofu	6.59	2.078	1942-1961
Nanyunhe	Jiuxuanzha	15.2	4.793	1920-1945
Zhanghe	Guantai	19	5.992	1942-1970
Haihe	_total_	152.178	47.991	
Haihe-Luanhe	_total_	181.8	57.326	

*Note: The basic in-stream flow of the Daqinghe River is the total amount of four stations, that is Zhangfang, Beihedian, Beiguocun and Zhongtangmei*

For the river systems in North China, the sediment carried out during the flood season may represents more than 80% of that of the whole year. The runoff in the flood season is the most important part of water for sediment transfer whereas that of the drought period can be ignored. For the maximum amount of water resources development and utilization, it is reasonable and rational to transfer sediment in the flood season, when the sediment transfer capacity is much stronger than in other periods.

With the assumption that the sediment content can be managed by some special methods and the sediment is transferred mainly in the flood season, the water requirement for sediment transfer ( $W_s$ ) may be calculated according to expression (2):

$$W_s = S_t / C_{max} \quad (2)$$

where  $S_t$  is the average amount of annual sediment transferred, and  $C_{max}$  is calculated by expression (3):

$$C_{max} = \frac{1}{n} \max_i (C_{ij}) \quad (3)$$

where  $C_{ij}$  is the monthly mean sediment content of the  $j$ th month in the  $i$ th year, and  $n$  is the number of the years under consideration. With the expressions (2) and (3), we have calculated the water requirement for sediment transfer in the flood season. The results are shown in Table 2, which indicates that the amount of water requirement for the major rivers in the Haihe-Luanhe river system is about  $63 \times 10^8 \text{m}^3$ .

### 3.3. Water requirement for lakes and everglades

The water required for lakes and everglades is the consumption of water to keep the aquatic eco-system to a certain level during a certain period in a year, mentioned just as an example. In the light of the water balance principle, for the natural situation without any water withdrawn, the balance of the lakes and everglades can be expressed as follows:

$$W_l = P + R_i - R_f - E + W_g \quad (4)$$

where  $W_l$  is the changing amount of the water stored in the lakes or everglades,  $P$  is the precipitation,  $R_i$  and  $R_f$  are the inflow and the outflow respectively,  $E$  is evaporation, and  $W_g$  is the change of groundwater amount.

Table 2. Water requirement for sediment transfer in flood season of major rivers in Haihe-Luanhe river systems

Rivers	Stations	Sediment transferred/ $\times 10^4 \text{T}$	Sediment content / $\text{kg/m}^3$	Water requirement for sediment transfer / $\times 10^8 \text{m}^3$
Luanhe	Luanxian	2670	10.700	24.953
Jiyunhe	Jiuwangzhuang	13.3	1.170	1.137
Chaobaihe	Suzhuang	35.3	1.520	2.322
Yongdinghe	Guanting	139.8	4.840	2.888
Daqinghe	Baigou	240	2.320	10.345
Daqinghe	Xinzhen	107	4.290	2.494
Ziyahe	Xianxian	232	2.250	10.311
Fuyanghe	Hengshui	47.2	1.170	4.034
Hutuohu	Huangbizhuang	852	18.890	4.510
Total	-	-	-	63

For a certain environmental and ecological function of the lakes or everglades, the storage of water can not be changed a lot. In the yearly scale, it must be equal to zero, that is  $W_l = 0$  and the level of groundwater must be kept in a dynamic balance, which means  $W_g = 0$ . With regard to these aspects, for the rivers in North China, a certain amount of water is required for surface evaporation, which means that the amount of water requirement for environmental and ecological functions of the lakes or everglades is the net amount of water consumption by evaporation. Thus according to expression

(5), the amount of water requirement for the lakes and everglades ( $W_l$ ) in the Haihe-Luanhe river system is calculated.

$$W_l = A_i(E_i - P_i) \quad (5)$$

where  $A_i$  is the area of lakes  $i$  or everglades  $i$ ,  $E_i$  and  $P_i$  are the evaporation capacity and precipitation of the lakes or everglades concerned respectively.

The investigation of the Haihe-Luanhe river system (Liu Changming and Wei Zhongyi, 1989) shows that the Baiyangdian Lake and the Beidagang Lake are the two most important lakes of the system, with areas of 336 km<sup>2</sup> and 350 km<sup>2</sup> respectively, whereas the evaporation capacity and precipitation is 1,100 mm and 550 mm each. With the help of the expression (5), the water required for the lakes and everglades in the river system is about 4x10<sup>8</sup> m<sup>3</sup>.

#### **4. Discussion**

This paper shows that the total amount of water requirement for environmental and ecological purposes in the Haihe-Luanhe river system is about 124x10<sup>8</sup> m<sup>3</sup>, occupying 54.4% of the total runoff (228x10<sup>8</sup> m<sup>3</sup>) (Yu Fenglan *et al.*, 1994). The three aspects of the water requirement, including in-stream flow, water requirement for sediment transfer and water requirement for lakes or everglades, need 57x10<sup>8</sup> m<sup>3</sup>, 63x10<sup>8</sup> m<sup>3</sup> and 4x10<sup>8</sup> m<sup>3</sup> respectively.

Moreover, considering environmental and ecological problems, the results indicate the rate of water resources development and utilization must be kept in a reasonable range. The widely accepted rate for reasonable water resources development is about 30% whereas the extreme rate is not higher than 40%. In China, the average rate of water resources development is about 20%; in the southern part it is lower than 20% and in the northern part, much higher than 20%. Among those river systems in North China, the Liaohe River, the Huanghe River and the Haihe-Luanhe river systems all have a development rate higher than 50% and the Haihe-Luanhe river system reaches a value of 80%.

Because of water resources depletion, the phenomena of river channel drying-up, lake shrinkage and everglades disappearing in the Haihe River and the Huanghe River have become more and more serious. In addition, for there is not enough water for decontamination, with the increasing sewage discharge into the rivers, the three rivers mentioned above have become the most seriously polluted rivers in China. Drying-up of the channels and pollution of the rivers have made the aquatic species reduce greatly. And in some segments of the rivers, aquatic species are no longer in existence, hence the so-called "the dead rivers". All these have done great harm to the socio-economic development and to the health of the local people. One of the main reasons for environmental and ecological degradation in North China, especially in the Haihe-Luanhe and the Huanghe river systems, is the excessive utilization of water resources, which is out of proportion to the water required for environment and ecology. It must be noted that environmental and ecological water requirements of the river systems should be obligated in river system planning.

With regard to water resources development in the Haihe-Luanhe river system, the crisis of water resources is quite obvious. For such a system, it is very hard to meet the environmental and ecological water demand. Confronting such a situation, in order to improve the environmental and ecological functions of the river system, we need to take some positive measures such as saving water, reducing discharge of sewage and making use of seawater, rainwater and treated sewage water. In addition, adjusting the industrial structure to adapt to the water resources and enhancing the ability of water resources management may be helpful to ecological rehabilitation. The ambitious schemes for transferring water from the south of China to the north may also benefit the environment and ecology in North China.

As for the calculation of environmental and ecological water requirement, the following aspects need to be noted.

Firstly, in calculating the total amount of the water required, we do not consider the water requirement for solute transfer exclusively. It is just because for most rivers, if there is enough water for the basic in-stream flow and sediment transfer, solutes will be transferred at the same time.

Secondly, the water requirement for sediment transfer in the research is calculated under a certain assumption mentioned above. It is sure that the result may change with the assumption. Especially, when the adjustment of human activities is intensified, artificial sediment digging for example, the water requirement for sediment transfer will be reduced accordingly.

Thirdly, we must point out that the amount of water requirement in the river system depends on our demand for environmental and ecological functions. If the standard for a suitable environment and ecology is higher, more water may be required, and vice versa. Thus more precise calculation of the water requirement must be based on the ecological function planning. In practice, for some special problems in a certain region (groundwater over depletion for example), further research needs to be done before calculating. The result obtained here is just a general concept of the region.

Finally, since there is not a general definition of environmental and ecological water requirement, the results obtained have some limitations. We would like to point out that the amount of water calculated here is on the basis of environmental and ecological balance. It is different to the concept of water redistribution on the basis of water supply and demand balance. However, the definition we have discussed may have great advantages to reasonable development of water resources that avoids any potential ecological or environmental disasters and makes the development of society, economy and environment more harmonious (Li Lijuan *et al.*, 2000).

## **5 Conclusions**

In the history of water utilization and development, our attention was mainly paid to the benefits we got from rivers, whereas the environmental and ecological functions of



the river system used to be neglected. Thus, the activities of water utilization and development were accompanied by more and more serious environmental and ecological problems. In order to reduce the environmental and ecological problems induced by water resources development and utilization, this paper proposes a concept of environmental and ecological water consumption. According to the concept, the methods on calculating the amount of environmental and ecological water consumption are determined. In the case study on Haihe-Luanhe river system, the water requirement is divided into three parts, i.e., the basic in-stream flow, water requirement for sediment transfer and water consumption for evaporation of the lakes or everglades. The results of the calculation show that the environmental and ecological water requirement in the river system is about  $124 \times 10^8 \text{ m}^3$ , including  $57 \times 10^8 \text{ m}^3$  for basic in-stream flow,  $63 \times 10^8 \text{ m}^3$  for transportation of sediment and solutes and  $4 \times 10^8 \text{ m}^3$  for net evaporation loss of lakes. Thus, the total amount of environmental and ecological water requirement accounts for 54% of the amount of runoff ( $228 \times 10^8 \text{ m}^3$ ). It should be realized that the required amount of environmental and ecological water requirement must be more than that we have calculated. Regarding that, we consider that the rational utilization rate of runoff in the river system must be not more than 40%. Since the current utilization rate of the Haihe-Luanhe river system, which is as high as 80%, has been far beyond the limitation, the problems of environment and ecology are quite serious. It is urgent to control and adjust water development and utilization to eliminate the existing problems and to avoid the potential ecological or environmental crisis.

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