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The Research Progress of Ecological Water Requirement in China and Abroad

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Abstract

Based on the research results of the ecological water requirement both in China and abroad, this study divided the research process of the ecological water requirement into four stages .The embryonic stage of ecological water requirement from 1940s to 1970s, represents the rapid development of the in-stream flow methods and the preliminary discusses of the determination of the minimum stream flow. During this stage the formal view of the ecological water requirement was not formed. The view of the ecological water requirement was formed during 1980s, mainly represented the maturation of the study in stream discharge in foreign countries, the formation of the allocation study's embryonic of eco-environmental water requirement and the initial proposal of ecological water requirement problems .The broad scale research of ecological water requirement which have been a focus around the world from 1990s to the early 21st century, mainly represented the essential perfection of the conception of the ecological water requirement and the development of the related theory and methods. Since the21st century, the inclined maturity stage mainly represents the further study of the conception and the methods of all kinds of ecological water requirement.

Key words: ecological water requirement; calculation methods; ecological system; research; advance

The study of ecological water requirement is not only the base of water resource's rational allocation, development and utilization, but also the sustainable security to maintain and improve the ecological system, thus to realize the sustainable use of water resources. Under the circumstance of worldly worse-getting ecological environment, for the purpose of scientifically solving the water imbalance and ecology issues, the issue of the eco-environmental water requirement currently have become a hotspot of the eco-environmental study fields. In our country, the water supply is seriously scarce.The problems such as dehydration, water pollution, water wastage, unreasonable water management and ecological unbalance have gone from bad to worse with economy's rapid growth. So the study and probe of the ecological water requirement and the dynamic integration of its research results and the practical problems, has great scientific and practical significance.

1. Research Status Quo in China and Abroad

The study of ecological water requirement is still at the beginning stage and the feasible theory foundation is

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still insufficient. Based on the research materials of the ecological water requirement study both in China and abroad, the study of ecological water requirement could be divided into four stages:the embryonic stage (from 1940s to 1970s),the basic formation of the views (1980s), the broad scale research stage (from 1990s to the21st century), inclined maturity stage (since the21st century up to now).

1.1 The embryonic stage

The earliest studies dated from 1940s, in U.S. Fish and Wildlife Service began the in-stream flow study and firstly proposed the concept of riverine ecological flow for the purpose of preventing the degradation of riverine ecosystem. From 1950s to 1960s, the researches mainly focused on the quantitative and procedural studies of river ecological flow. From 1960s to 1970s, the investigation on the biological response to the change of the water stream made great progress. The important activator linking the water stream and the ecology was the book named *Riverine Ecosystem and Human*. However, at that time the river management was only an art, not a science. By the end of the 1970s, IFIM had been in widespread use in North America. In China, the water resource workers began and continued the studies on environmental capacity and the minimum stream flow until the end of the 1970s. The Chinese Yangtze River Water Conservation Committee and Government first conducted the research in *The primary exploring of environmental water*. By the end of the 1970s, the concept of ecological water requirement hadn't been put forward both in China and abroad. This stage is the first stage-embryonic stage.

1.2 The basic formation of the views

In 1980, UK, Australia, Asian, South America, etc. accepted the American concept of riverine ecological flow, and implemented broad scale researches. The in-stream flow methods had came to a perfect situation, containing historical flow, hydraulic quantity, habitat quantity and overall analysis. Nevertheless, it failed to explicitly offer the calculation of ecological water requirement. In the early 1980s, with the problem of river pollution came into existence, America began the study in connection with the minimum acceptable stream flows which not only met the shipping, biology, and landscape water requirement but also met the drainage and waste discharge which formed the embryo of eco-environment water requirement's study (Armentrout G W et al.1987; Hughes D A, 2001; Henry C P et al. 1995;Henry C P et al.1995; Geoffrey E P,1996)

In China, the initial view of the ecological water requirement generated during the management of the water resources in arid areas. By the end of 1980s, Tang Qi cheng et al offered *Ecological Water Use*, which meant *to ensure the existence and the development of the oases in Tarim Basin*. *The water needed for the protection of the ecological environment is called the ecological water use.* In China, the studies of ecological water requirement centre on the human and it seldom considers the water requirement of the natural ecology environment. That is determined by Chinese natural condition. The hydrological situation in China is complex and the areas of the arid and semi-arid regions are larger, leading to a serious water shortage (Chen, 2007) ， however, the hydrological regime in the United States and Europe is regular; the population pressure is less; the water is sufficient and the state of nature is better. Therefore, more consideration turns to the protection of biodiversity at abroad. Another feature of ecological water requirement in 1980s of China is the studies mainly focused on the macro-strategic aspect. The problem of how to manage it is still at the exploratory stage.

1.3 The broad scale research stage

From 1990s to the beginning of the 21st century, with the strengthening of human impact and control on the ecological environment, water resources, water environment and the increase of ecological problems of water, people were forced to re-examine the relationship between water resources and ecosystems.Eco-environmental water requirement became one of the key problems in the world. China's Ministry of Water Resources formally proposed the eco-environmental water requirement should be considered in the allocation of water resources. *The Ninth Five-Year* national key scientific and technological project *Water Resources and Environment Assessment of the Arid Region of Northwest* first explicitly put forward the operational calculation method of *Eco-environmental Water Requirement.* Chinese Academy of Engineering organized and implemented the *Water Resources Strategy's Comprehensive Report of China's Sustainable Development* which preliminarily offered the theory of ecological water requirement, estimated the nationwide ecological water and considered the ecological and environmental water issues in the allocation of water function across the country. In 2001, UK Department of the Environment analyzed the community and environmental water requirement for the next 25 years and offered 730 action steps in the report of "Face to the Future Water ". With extensive research of ecological water demand in China and abroad, the concept and the accounting method of the ecological water requirement had been further developed.

1.3.1The concept

At this stage, there were many domestic and overseas scholars studying the concept of ecological water requirement in many ways and had achieved some fruitful research results. The main representatives abroad are

Covich's definition of the ecological water requirement and Gleick's (1998a, 1998b, 2000) proposal of the concept of ecological water requirement. In China, the main representatives are Tang Qicheng, Jia Baoquan and Xi Longjun. Jia Baoquan offered the concept of ecological water requirement in arid areas. It is *In the arid zone, all the water consumption of the systems which play a supportive role to maintain and improve the survival and development of the oases and quality of the environment*(Jia et al.1998). This is by far the most detailed research result about concept and classification of ecological water use. Additionally, Liu Changming, in accordance with the relationship between water resources development and ecological water use, proposed the "Four Balance", probed the sharing among "Three Vital Water" (live, production, ecology), and distinguished the ecological and environment water requirement between broad and narrow senses.

At this time there were many concepts which were similar to the concept of eco-water requirement, environment water requirement,ecological water consumption,ecological restoration, ecological and environment water requirement and so on. Many domestic investigators have discussed these concepts.

1.3.2 The research approaches

At this stage, the worldwide scholars extensively integrated the theory and the methods of hydrology and water resources, then made hydrology and ecology have a solid foundation and connotation (Wang et al. 2002;Li et al. 2000;Qian et al. 2001; Petts GE.1996; Hughes DA. 2001; Thomas MC et al. 2002). Ecological water requirement become a hot research field in the studies of ecology, hydrology and water resources. Domestic research methods of eco-environment water requirement mainly concentrated in terrestrial ecosystems and riverine ecosystem, and the research methods mainly directed to the northwest arid region. The calculation methods usually were "Fixed Area" or "Fixed Plant" and the theory of computation are the traditional water balance one, therefore,the calculation methods were more mature（Jia et al. 2000;Fan et al. 1998）. Along with the research of eco-environmental water requirement, the studies had extended to off-stream ecological systems, such as lakes,wetland, and river delta, but for the calculation methods of off-stream ecological systems,a complete set of mature calculation method was not formed.

1.4 Inclined maturity stage

1.4.1The scale and outcomes

(1) The study scale

Since the 21st century, in a world wide scope, the studies of ecological water requirement focus on two scales which are the regional scale and the scale of all kinds of ecological systems. At abroad, regional studies of ecological water requirement still mainly concentrated on the conservation of the biodiversity, with Thomasson (2004), Schuluter, etc. (2005) as representatives. China's studies of regional ecological water requirement with Si Jianhua (Si et al.2005) and Wang Genxu (Wang et al. 2005) as the representatives, mainly concentrated on the arid and semi-arid areas with severe contradiction between supply and demand, and in Haihe River Basin and Heihe River Basin, there were very serious water shortage. In recent years, in China,it is preliminarily studied the south, coastal areas and the county's ecological water requirement with Han Zengcui,You Aiju (Han et al.2006)and Qi Honggang (Qi et al.2010) as the representatives.

By overviewing the study areas of ecological water requirement, it is found that the study scope of the ecological water requirement were too broad, such as the studies of Yellow River, Hai River Basin, and eco-environmental water demand in North China. For small scale, such as county or ecological water requirement of the island were seldom reported. Considering the studies of all ecosystem's ecological water requirement, the domestic and international researches have concentrated on the river (lake)(Li et al.2000;Gleick PH,1996;Chen et al.2009;Feng et al.2003), wetlands(Feng et al.2008;Cui et al.2003), woodland (vegetation) (Zhang et al.2002;He et al.2004;Min et al.2004;Zhang et al.2003) ,urban (Ma,2007) and other ecosystems.

(2) Findings

Since the 21st century, a lot of meaningful research results of ecological water requirement in China and abroad have been made. At abroad, the results were summarized in the FRIEND (Flow Regimes and Network Data) Action Plan Report. So far, overseas research on ecological water requirement still concentrated on the in-stream. It can be summarized in the following areas: the studies of the relationships between in-stream flow and fish habitat, the studies of the relationships among river flows,aquatic life and dissolved oxygen (DO), the studies of the relationships between aquatic biological indicators and flow,the studies of optimization disposition of ecological environment and ecological environment water flow in the reservoir dispatching, the studies of the relationships between the ecological water use and economic water use, etc. In the domestic research enthusiasm of ecological water requirement, some scholars made many innovations combining the situation of China. Zhang Xiangwei carried out more detailed relational studies between ecological water requirement and ecosystem (Zhang,2005).

Zheng Hongxing researched the theories of the ecological effects of the water cycle (Zhen et al.2004). "Tenth Five-year" national key scientific and technological projects offer "The Study of China's Standard of Sub-regional Ecological Water Use". Zhang Guangdou, Qian Zhengying, Li Jiuyi made ecological water requirement widely apply to water resources allocation and the protection of ecological environment, etc. (Li et al.2006; Zhang, 2000).Cui Baoshan offered the study of the mutual feedback between ecosystems and hydrological process(Cui,2005); Cui Baoshan, Yang Zhifeng, as representatives, offered the studies on river basin scale and river basin's hierarchical computation (Cui,2003).

1.4.2 The concept

Since the 21st century, foreign scholars talked little over the concepts of ecological water requirement. The main researches of the concepts are concentrated in China. According to the applicability of different ecosystems, Zhang Li and Li Lijuan , divided the concept of ecological water requirement into two levels: one is a broad concept for the precipitation, the other is a narrow concept for surface and groundwater resources. Broadly the ecological water requirement can be understood as the total amount of water needed, under certain ecological goals, to maintain the water balance (including water and heat balance, water and sediment balance, water and salt balance, water balance) in appropriate spatial and temporal scales. The broad concept applied to the description of land ecosystems (forests,grasslands, etc.) and aquatic ecosystems (rivers, wetlands, marshes, lakes, etc.), has universal significance whether in the ecological vulnerable arid and semi arid areas with obvious contradiction between supply and demand of water resources, or in the moist areas with rich water and serious water pollution. The narrow ecological water requirement, under certain ecological objectives, is the amount of runoff resources needed to be supplemented to maintain the normal ecology and environment function.

So far, the concept of environmental water requirement has not been uniformly defined. Most of the studies included the environmental water requirements in ecological water requirement, while other studies included ecological water requirement in the environmental water requirements. Although these terms are similar, strictly speaking, there are still many differences. Anyway, there is a unified view in the respect of supporting ecosystem integrity and maintaining ecosystem health.

1.4.3 The research approaches

Since the 21st century, international calculation of river ecological water requirement has become comparatively mature. It can be divided into four categories: the hydrology methods, hydraulics method, habitat simulation method and synthetic method. In these computational methods, hydrology is the simplest and the most representative one. China's calculation methods of water requirement of river ecosystem are the traditional method to set the standard flow, habitat method based on the biological foundations, hydraulics method based on the basic hydraulics. Estuarine ecosystems are very complex. Because few people study ecological water requirements of estuarine ecosystems,here are not relatively mature calculation approaches for estuarine ecological water requirement. What's more, research methods of off-stream ecosystems have become a comparatively mature system.

International research approaches of lake's ecological water requirement are mainly water balance method, water turnover rate method, functionalist approach, minimum water level, natural water level data statistics , lake morphological analysis and minimum requirements of biological space. Because of the lack of sensitive species and the lack of studies of the relationship between sensitive species and the water environment research, the minimum water level method which is offered by Yang Zhi-feng etc. is more suitable for the calculation of lake ecological water requirement.

Presently, the theory, method and application of vegetation ecological water requirement are at an exploratory stage. There are still many shortcomings in theory system and the calculation methods. The mainly calculation methods both in China and abroad are area-quota method, evaporation method, the modified Penman equation method. The wetlands calculations involved in wetlands, ecology, hydrology, environmental science, soil science and botany and other multi-discipline knowledge. Although there are many calculation methods such as empirical statistics analysis and simulation modelling, the unified method hasn't formed. Because the restrictions of the data acquisition ,domestic ecological water requirement study of wetland without applying the example of simulation modelling, mainly based on experiential statistical analysis technique which include wetland classification method first proposed by Cui Baoshan and Yang Zhifeng and eco-hydrological analysis method first proposed by Zhong Ping,etc(Zhong,2005).

With the development of remote sensing and GIS, remote sensing methods have become an important method for the study of various ecosystems' ecological water requirement. The main principle of remote sensing is going through a remote sensing interpretation and spatial analysis in GIS environments to obtain the parameters or ecological water requirement flow of each ecosystem for the calculation of various ecosystems' water requirement.

In recent years, a large number of domestic scholars use this method with Wang Fang (Wang, 2002), Cui Lijuan (Cui et al.2006), Tang Yun (Tang, 2005), Dai Xiangqian(Dai et al.2007), etc. as representatives

In general, the calculation method of the eco-environmental water requirement has made some progress, and has provided a fundamental basis for rational utilization of water resources. However, owing to the complex relationship between water and ecological, unified sub-area of various types of ecosystems, non-standard computational methods, unsound assessment and management system, non-quantitative human factors, etc. (Fen et al.2003), the calculation of ecological water requirement basically stay on the qualitative analysis and marco-quantitative analysis. It can't fully and truly reflect the actual situation, and the results may have greater risk (Zhang,2007).What's more ecological water requirement is related to climate, hydrology, geography, geology, socio-economic ,the computing methods of eco-environmental water use abroad may not be suitable for China.

2. Research Prospects

The research of ecological water requirement is still in the initial stage. The most part of the researches still focus on the exploratory of the concept and the connotation of ecological water requirement. On the basis of summarizing previous work, the author thinks that the ecological water requirement is the water which must be consumed to maintain an eco-system structure harmonious and stable to normally play its ecological functions, or the water to maintain the ecological environment with no further aggravating.

In respect of the ecological water requirement's research methods, a relatively mature calculating method system of riverine ecological water requirement has been formed both in China and abroad, but the studies of the off-stream ecological water requirement are still at an exploratory stage.

According to some problems of current ecological water requirement's studies and the development trend of the discipline, the writer utilizes some scholars' research results, then thinks that the future researches of ecological water requirement should be strengthened from the following aspects.

(1)Strengthen the theory studies of ecological water requirement. So far, the concepts of environmental water requirement have not been uniformly defined in the connotation and the extension and haven't formed complete theoretical system. What's more, the distinctions among the similar concept are blurred. There are many disputes on whether to differ the ecological water demand from the environmental water demand. People should strengthen the study of theory system, and reasonably identify the concepts, the connotations and the extensions of ecological water requirement and environmental water requirement. Thirdly we should study the classification of the eco-environment water requirement, the formation mechanism of different kinds of eco-environmental water requirements, the internal and external factors affected the ecological and environmental water requirement.

(2)Strengthen the quantitative, scientific and adaptive studies of the ecological water requirement. People should strengthen the quantitative studies of regional minimum ecological water requirement and regional ecological and environmental water requirement; simultaneously people should delve into the studies of evaluation index system and method of regional eco-environmental water requirement. Secondly, owing to the insufficient understanding of hydrological process and mechanism, the lack of scientific data's accumulation, the fuzzy and compatible division boundaries in the specific types of ecosystems' calculation, the non-scientific aspect of ecological water requirement is limited. Thirdly, since the conditions vary from area to area, if the range of study is surely overbroad, the method's suitability will reduce. In the future, we should strengthen studies from the following: last scale and typical region's ecological water requirement, such as county ecological water requirement's study; ecological water requirements of all kinds of ecosystems and the rules of spatial and temporal differentiation containing the comparative studies of different space time pattern in a same ecology; all kinds of ecosystems' studies except for the arid and semi - arid regions, such as Taihu Basin and Qiantang River basin in subtropical zone.

(3) Emphasize the theoretical guidance and the applied research of ecological water requirement. The ecological water demand's computing method is mainly based on current situation,and less predict for future years . As far as it goes, since lack of rational analysis and diagnosis of status of ecologic environment and the principles and objectives of ecological protection are not specific, so it is difficult to accurately determine the practical value of research results. From now on, we should strengthen the ecological water requirement's application to the water resources allocation and ecological environmental protection. Through scientifically checking ecological water requirement, people should analyze the human activities' influence on the ecological water requirement and the regional ecological and environmental problems' influence degree to the social economy. It can provide a scientific basis for the rational allocation of water resources and ecological environment's protection and restoration.

(4) Strengthen the research of interdisciplinary integration; promote the application of new methods and new technology to the study of ecological water demand. Currently the facilities and technical means for ecological water research haven't been perfect. Because the ecological water requirement covers different levels and disciplines, from theory to empirical, from discipline of the water cycle and evolution in the macro-environmental changes to the catchments hydrology and water consumption mechanism of vegetation in the micro field, from the hydrology and water resources science to social economic sciences and programming science, etc. therefore, the need of strengthening the course construction is urgent. People should strengthen the combination of new methods and new technologies with hydrological models and ecological models, should manage the spatial and non-spatial data, should identify best environment time-periods and maintain favourable ecological environment.

(5) Combine the ecological water requirement with the process of sustainable development. People should fundamentally promote the restoration and reconstruction of the damaged ecological environment system and the rational distribution of water resources, particularly the eco-environmental water use, which is very important. This involves people's concept change of using water, as well as the establishment of water resources' development and utilization strategy taking the harmonious development of eco-environmental protection and rational development and utilization of water resources as the goal. Taking the road of sustainable development is China's own needs and the inevitable choice. As pointed out in the synthesized report of China's Strategy of Sustainable Development of Water Resources, the total strategy of China's water resources must use the "Sustainable Use of Water Resources" to support continuous development of social economy. The achievement of the goal depends on the reasonable determination of ecological water requirement. It is only through ensuring the water demand of eco-environment, that we can achieve rational allocation of water resources and ensure the coordinated development between social system and ecological system.

3. Conclusion

This article reviewed the progress of ecological water requirement both in China and abroad and divided the research process of ecological water demand into four stages.

(1) The embryonic stage before 1970s. The foreign scholars who mainly took the prevention of the riverine ecosystem's degeneration and the protection of biodiversity as the goal, researched the in-stream flow, and proposed the concept of riverine minimum biological flow and formed IFIM. China preliminary study of the environmental water at the end of 1970s, but only probed the minimum flow of the river. In this stage, the concept of ecological water requirement was not put forward.

(2) The view of ecological water requirement basically formed in the 1980s, and the extension of the concept of riverine biological flow first offered by America in 1970s, preliminarily studied the drainage function and formed the beginnings of the allocation study of eco-environmental water requirement. In this stage, China mainly studied the arid regions with lacking of water and offered the issue of ecological water use, but the starting point of studies mainly aimed at human water requirement, without achieving the real combination between ecology and environment.

(3) From the 1990s to the early 21st century, the ecology water requirement had been widely researched .At this time it is extensively researched the concept of ecology water requirement and the relevance between water resources and the ecological environment internationally. Within this time all the scholars integrally studied the water resource, ecosystem and human society as a whole and brought it into sustainable development, and then carried out broad studies of ecology and environment water requirement. It is extended the research of ecology water requirement to the studies of forest land, wetland and the city.

(4) Since 21st century, the studies of ecological water requirement incline maturity. In this stage, the international constantly improve the concept and calculation methods and basically formed the riverine ecosystem, but the suitability and scientific are still in the initial stage of exploration. At this stage, the concept' research of ecological water becomes more specific in this period, and the comprehensive studies of the ecological water requirement and hydrology ecology are strengthened. The research of sustainable development of ecological environment is also brought into the research process of sustainable development, but the environment standard, related theory and the implementation method of sustainable development haven't been formed yet.

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