Research on environmental flow in Huai River Basin, China

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Abstract. The estimation methods for environmental flow were discussed in this paper. Based on the comparative analysis of calculation methods of environmental flow, a "Huaihe Method" was proposed, which consists of the hydrological estimation of the minimum environmental flow with validation by the requirement space for fish. The minimum environmental flows of the important control sections in main stream and tributaries in the Huai River basin are estimated. The recommended minimum environmental flow has been adopted in the water resources planning, which provided reference for rational allocation of environmental flow, water resources usage, and sustainable development for the local society.

1. Introduction

With the area of 270000 km², Huai River basin is situated at China's north and south climate intermediate belt. North of the basin has been facing inadequate water issue for the temporal and spatial uneven water resources distribution. At present, water ecological system in most parts of the Huai River basin has been affected by extremely water resources exploitation for economic development. A larger amount of dams have been constructed on the main stream and tributaries in Huai River for domestic, industrial, and agricultural utilization. There are various problems in water ecosystem. Research on environmental flow has become the key way to maintain ecosystem health of the Huai River.

Combined with the development of the study on environmental flow and based on the comparative analysis about calculation methods of environmental flow, the minimum environmental flow of the important control sections in the Huai River basin is introduced. Finally, the prospective research on the ecological water requirement was proposed, so as to provide reference for rational allocation of environmental flow in future.
2. Development of research on environmental flow

Environmental flow is the amount of water needed in order to maximize the improvement of natural ecological system and maintain ecosystem integrity, and ensure the biodiversity of natural habitat. The concept was first proposed by Gleick[1] in 1996, but the research on environmental flow began in the 1940s. More than 70 years of study can be divided into three stages.

- Establishment of relevant concepts: In the 1940s, the U.S. Fish and Wildlife Conservation Association studied the relationship between fish growth and reproduction and river flows, and first proposed the concept of "In-stream Flow Requirement"-minimum river environmental flow in order to avoid the river ecosystem degradation. During this period, the concept of environmental flow was not clear, but some rules about flow compensation began to be developed and implemented.

- Quantitative study of environmental flow: In the 1950s and 1960s, the quantitative study on river environmental flow and research based on process started. Scholars focused on the energy flow, the carbon flux, and large invertebrate life history[2]. In the 1970s and 1980s, the relationship of fish growth to river flow was studied systematically in view of river ecosystems in the United States, Australia, South Africa, France, Canada, and other countries. There were some calculation and evaluation methods developed in this period. Preliminary research results have been achieved [3].

- The overall analysis of the ecosystem: Since 1990s, through study on correlation between water resources and ecological environment, environmental flow became one of the focuses of the world. The concept of environmental flow for a river was clearly put forward. Research objects extended from species (such as fish and invertebrates, etc.), and river physical form to maintenance of river flow considering the integrity of river ecosystem. At this point, some new research methods have appeared, such as BBM (Building Block Methodology) method, the overall analysis method and model simulation method based on the relationship between river flow and aquatic habitat.

Research on environmental flow in China began in the 1970s, which mainly concentrated on the determination of river environmental flow.

In the 1980s and 1990s, study on environmental flow aiming at ecological environment deterioration in the northwest inland areas began firstly in the northwest arid and semi-arid areas[4]. Then, due to the discontinuous flow, siltation, river pollution, and other issues, scholars conducted research on environmental flow for rivers and lakes in Huang-Huai-Hai plain[5].

Since the 21st century, the study on environmental flow matured unceasingly in China. The analysis system of ecological water standard base was built in the national science and technology research project "Research on standard of regional ecological water in China". Characteristic value of environmental flow and ecological water control indexes of different development stages of four large river basin in the northern semi-humid and semi-arid areas were put forward[6]. Ecological water needed by ecosystem restoration in the Huang-Huai-Hai plain was studied by Ministry of Water Resources. Environmental flow have
been known as content in the balance between supply and demand that must be considered in the projects such as water resources configuration of South-to-North water transfer, coordinated development between water conservancy and national economy, and the new planning of national water resources. The importance of ecological operation has been more emphasized during construction and operation of Xiaolangdi Reservoir [7]. At the same time, some scholars have carried on thorough studies on modeling environmental flow. China's first model of aquatic habitats fitness based on long series of field data has been established by Fengqing Li[8].

3. The calculation method of environmental flow for rivers
At present, there are as many as 200 calculation methods about environmental flow. These methods in general can be classified into four categories: hydrological methods, hydraulic methods, habitat simulation (or evaluation) methods, and entirety analysis methods.

- Hydrological methods: This method for environmental flow is based on historical flow, which has more advantages on the data collection cost than other methods. This method is a basic means in the research of environmental flow. The common methods are Tennant method, 7Q10 method, basic flow method, monthly frequency calculation method, etc. Among them, Tennant method is the most commonly used in China. Tennant method takes a percentage of annual average discharge as base flow, which is conformed to the environmental flow estimation demand for seasonal rivers. This method has the macroscopic qualitative guiding significance [9]. The method was implemented in rivers at Virginia region of the United States. 10% of the annual average flow is degraded or barren habitat conditions, 20% of the annual average flow provides appropriate standards to protect aquatic habitats, and 30% of annual average flow is close to the best standard of habitats in the small river[10].

- Hydraulic methods: Assuming that river physical form remains the same, river flow at downstream can meet the requirements of river ecological function when a section of the river satisfies a certain flow. The commonly used methods are wetted perimeter method, R2 - Cross and CASIMIR methods.

- Habitat methods: This method determines that the recommended flow is suitable for aquatic organisms survival based on the ecological hydraulics. Main methods are effective width method, the river flow increase method, etc.

- Entirety analysis methods: Starting from the whole ecological environment in the study area, the method determines the recommended value of flow through the comprehensive research on the relationship among river flow, sediment transport, bed configuration, and the riparian zone. The recommended value can simultaneously satisfy the overall ecological functions including biological conservation, habitat maintenance, erosion and siltation, pollution control and landscape maintenance, etc. Methods mainly include BBM (Building Block Methodology) method and the overall evaluation method [11, 12].

The advantages, disadvantages and scope of application of various calculation methods of environmental flow are summarized in table 1[13].
| Method                  | Advantages                                                                 | Disadvantages                                                                                                      | Scope of application                                      |
|------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| Hydrological method    | Simple; need least data; don not need extensive field work.                  | Lack of biological basis; Not considering seasonal variation and plentiful and withered circulation of flow; Environmental flow is often expressed in minimum; Historical flow data for years are needed. | River macro strategy management; The areas less controversial and no high priority. |
| Hydraulic method       | Data acquisition by measurements or Manning formula; Measurement is relatively simple. | Not considering velocity changes; Not considering needs of specific species and life stage; Not considering channel instability with time; Selected section cannot represent the whole channel characteristics. | Small and medium-sized rivers (with top width less than 30 m wide) where pollution is not obvious and sediment content is low. |
| Habitat method         | Considering the change of the habitat by species and its different stages of life. | Only consider the individual species, not considering the entire ecosystems; Need more biological data; Take a long time; Capital amount is big; Need a lot of field work. | Small and medium-sized habitat or the region of clear management objectives |
| Entirety analysis method | Considering the river ecosystem integrity; Satisfy variety of functions including biological conservation, habitat maintain and pollution control, etc. | Many subjects involved; Need expertise in ecology, geography, hydrology, etc; Consume a large amount of human resources and time cost. | Widely used in South Africa Currently; need a lot of correction when applied to other areas. |
4. **The determination of environmental flow of the important control sections in Huai River.**

Through the relevant research results of comprehensive analysis in Huai River basin and summary of the environmental method, “Huaihe Method” is put forward as the calculation method of minimum environmental flow on the basis of Tennant method for the data availability. The river stages are raised at comparable higher level by the dense distributed dams along the main streams. The results of the survey about Tennant in Nebraska, U.S., have confirmed that 10% of the average annual flow provides the smallest habitat conditions for river ecosystem. For large rivers, 5%～10% of the annual average flow can maintain certain number of river flow, water depth and velocity. The flow can meet general requirements of the fish migration, fish survival, tourism and landscape. It is instantaneous minimum flow to keep the vast number of aquatic life for a short period of time. Thus, 5%～10% of the annual average flow was adopted as minimum environmental flow to keep the survival of most of aquatic organisms in a certain time. At the same time, the minimum water requirement space of fish was selected to correct the estimated environmental flows in the main stream and tributaries of the Huai River.

The main stream of Huaihe, Honghe and Yinghe have relatively stable and larger flows, while meso flows exist in Guohe according to the historical records at hydrological stations. For rivers with flow rates less than 80 m³/s, 10% of annual mean discharge is allocated for environmental flow. The 5% of annual mean discharge is assigned for environmental flow when the flow rates are larger than 80 m³/s. At the same time, minimum water requirement space of fish is calculated with the discharge and geometry of cross-section for validation of estimated environmental flow. The validated environmental flows at selected cross-sections can maintain minimum space for growth and reproduction of zoobenthos and plankton. Based on results of analyzing monthly average flows, the environmental flows are expressed for the dry season (October to March), period before flood season (April to May), and flood season (June to September), respectively. Then minimum environmental flows of main river section during the year are determined consequentially.

Huaihe method not only retains the simple and quick method of hydrologic index method, but also has a solid foundation of ecology through the hydraulic calculation based on ecological analysis. The hybrid method which combined by different methods can compensate for each other. Huaihe method is more efficiency and reliability. It can be used for the study of ecological water use of watershed planning scale and also can be used as the basis for further research.

Results of this method were adopted in Comprehensive Planning of Huai River Basin (2012-2030). Minimum environmental flows at seven sections in Huihai, Yinghe, Guohe, Yihe, and Shuhe were determined with proposed methods. The selected seven sections include Wangjiaba, Bengbu, Xiaoliuxiang, Jieshou, Bozhou, Linyi, Daguanzhuang. The final control indicators of minimum environmental flow are listed in table 2.

**Table 2. Minimum environmental flow results of important river control section.**

| The name of the river | Section | Minimum environmental flow(m³/s) |
|----------------------|---------|----------------------------------|
|                      | October to March | April to May | June to September | The annual average |
| Huaihe               |             |               |                 |                  |
| Yinghe               |             |               |                 |                  |
| Guohe                |             |               |                 |                  |
| Yihe                 |             |               |                 |                  |
| Shuhe                |             |               |                 |                  |

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5. Perspective of environmental flow in Huai River basin.

The application of the results in the Comprehensive Planning of Huai River Basin (2012-2030) indicates that the Huaihe River Basin will be officially putting ecological management into the management of the river basin.

Based on the recent studies of ecological water demand and the current situation of environmental flows in Huai River basin, we summarize the recent and future research focus, mainly in the following aspects:

5.1. Dynamics and coupling of environmental flow

River environmental flow is a dynamic value, which varies with the change of the seasons, times, and sections. River environmental flow is closely related to environment protection. For the moment, researchers focus on individual research on ecological water demand. However, for the total water demand in the area, the environmental flows cannot be achieved by simple addition or subtraction because of the overlapping water problems. Therefore, in the future studies, we should consider the watershed ecosystem from holistic point of view. By studying the status and mechanism of water cycle in each ecosystem, the ecological water demand would be solved by establishing a coupling model. With such a model, we can more scientifically determine the ecological water demand. Furthermore, research should be clearly carried out at different temporal and spatial scales. Finally, we should also strengthen coupling study about the water quantity and water quality.

5.2. Multi-methods and application of 3S (RS, GIS and GPS) and other technologies of ecological water demand.

Existing individual quantitative methods about ecological water demand are flawed, which are still non-unified and sophisticated for China's ecological environment construction. Therefore, various methods can be combined to overcome their own weakness. Such as hydrological-hydraulic method proposed by the researchers. In addition, the determination of environmental flows with strengthening GIS and remote sensing technology on the measurement and calculation of relevant data could be expected. A wildly acceptable quantitative method for estimating the environmental flow satisfying multiple objectives at various temporal scales will be accomplished with multiple approaches.
5.3. Establish evaluation system of ecological water demand.
Currently, due to the lack of reliable evaluation criteria, we cannot verify the correctness of the results of the ecological water demand. Therefore, the needs for a large number of field measurements are to establish evaluation criteria that can adapt to the sustainable development of Ecological Water Demand for Huai River Basin. The establishment of the ecological water demand system that associated with the biodiversity, habitat, and ecosystem health should be implemented.

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