Calculation of the instream ecological flow of Shifengxi River in Zhejiang Province, China using hydrology and section morphology analysis method

C C Tian¹⁴, F Zhou¹ and D J Huang²³
¹Zhejiang Design Institute of Water Conservancy and Hydroelectric Power, Hangzhou 310002, China
²State key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing 210098, China
³College of Water Resources and Environmental Engineering, Zhejiang University of Water Resources and Electric Power, Hangzhou 310018, China

E-mail: tianchuanchong@163.com

Abstract. The instream ecological flow is one of the most important obligatory targets of water resources development and utilization, as it is the premise and basis for sustainable water resources development and water ecological environment protection. This paper proposed an instream ecological flow calculation method based on hydrology and section morphology analysis. The method had a certain concept of guarantee rate, and also considered the hydrological habitat requirements of the river section. The application of the method in Shifengxi river basin located in Taizhou city shows that the instream ecological flow of the Shaduan section is 14.0 m³/s during the spawning period and 3.1 m³/s during the normal period.

1. Introduction

Water resource play an important role in sustaining human survival and social development, which is also of great significance to ecological environmental protection. The contradiction between supply and demand of water resource is becoming more and more acute due to the continuous increase of production and domestic water. Excessive exploitation of water resource has occupied part of the ecological water quantity, and the ecological problem is becoming more and more obvious [1-3]. Some instream ecological flow calculating methods applied to the single river have been developed into maturity, which could be basically classified into: hydrological, hydraulic rating, holistic and habitat method [4]. Each method has its own adaptive condition and emphasis. The hydrology and hydraulics rating methods have the advantages of simple computation and easy handling, but failed to take the different instream ecological flow demand of species during various life stages into consideration [5]. The holistic and habitat methods take many factors into account, including water depth, velocity, temperature etc., and long-term and in-depth observation of ecosystems is also needed. Therefore, the two methods are relatively restricted [6-8]. So, this paper proposed an instream ecological flow calculation method based on hydrology and section morphology analysis (HSMA). The method integrated the advantages of hydrology and eco-hydraulics, and not only had a certain concept of guarantee rate, but also considered the hydrological habitat requirements of the river section.
2. Study area and datasets

2.1. Study area
The Shifengxi river basin is located in Taizhou city, Zhejiang province, China. It flows through Tiantai and Linhai county. The elevation of the watershed ranges from -3 to 1,235 m, with an area of 1,610 km², and its main stream length is 133 km with gradient of 2.8‰ (figure 1). As the continuous accumulation of population and the development of industry and agriculture, the need of water resource in the basin continues to increase [9]. Thus, in order to maintain the basin ecological stability and economic development at the same time, it is quite essential to calculate the instream ecological flow. The Shaduan hydrological station is located downstream of the Shifengxi river and controls the basin area of 1,482 km² (figure 1). Considering that the basic data of Shaduan section is very comprehensive, therefore, we select the section as the study site to determine the appropriate instream ecological flow based on HCMA method.

[Figure 1. Location, elevation and water system of the study area.]

2.2. Data sets
The data used in this paper included cross-section data and daily measured flow from 1961 to 2017 of Shaduan hydrological station. Cross-section data were obtained from actual measurements in 2018, and the daily measured flow were provided by Taizhou Water Conservancy Bureau.

3. Methods
Based on historical hydrological data and river section data, the HSMA method used hydrological frequency analysis and hydraulic parameters calculation to determine instream ecological discharge. The steps in detail were as follows:

- Division of computing period. The calculating period was calculated by the runoff temporal distribution and the habits of aquatic organisms.
- Hydrological analysis. On the basis of the long series hydrological data section, the runoff frequency during the different calculating periods could be calculated by day, month and ten-days respectively, and the ecological flow could be figured out preliminarily.
- Section hydraulic analysis. By calculating many factors, including the river width at different water levels, flow area, average water depth, maximum water depth, wetted perimeter,
hydraulic radius, flow rate, discharge volume, etc., the relationship curves between velocity, water depth and discharge volume could be illustrated firstly. Then, the ecological water-depth and flow rate of the control section that have been determined would be employed to calculate the instream ecological flow.

- The instream ecological flow determination. Through comprehensive analysis and judgment, the suitable ecological flow of the selected section was finally determined.

4. Computation and discussion

4.1. Division of calculating period

According to daily runoff data from 1961 to 2017, the annual average discharge of Shaduan was 37.3 m³/s. In view of the runoff temporal distribution (figure 2), it was fairly evident that the high flow period was from April to September, of which the discharge volume accounts for about 72% of the annual flow, and the low flow period was from October to March. In addition, it is known that the fish spawning period in the Shifengxi river is usually from April to September from Qihaiming [10]. Therefore, taking both runoff temporal distribution and the fish spawning season into account, the whole year is divided into two calculating periods to analyse the instream ecological flow. And the two periods include the spawning period (from April to September) and the normal period (from October to March of the following year).

![Figure 2. Average monthly flow distribution of the study area.](image)

4.2. Instream ecological flow calculation based on hydrological analysis

| Frequency | Flow during the spawning period (m³/s) | Flow during the normal period (m³/s) |
|-----------|---------------------------------------|-------------------------------------|
|           | Daily                                 | By ten-days                         | Monthly                            | Daily | By ten-days | Monthly |
| 80%       | 11.4                                 | 14.47                               | 20.95                               | 4.67  | 5.44        | 6.62    |
| 90%       | 6.4                                  | 8.87                                | 15.06                               | 2.42  | 2.74        | 3.87    |
| 95%       | 3.7                                  | 5.74                                | 8.15                                | 1.50  | 1.68        | 1.93    |

According to the measured flow data, the runoff frequency during the two periods (the spawning period and the normal period) is carried out by day, month and ten-days respectively (table 1). It is can been seen directly that the runoff volume of the ten-days period is between the day and the month under any hydrological frequency, closer to that of day period. At any hydrological frequency, the runoff volume in the mouth period and ten-days period is about 2 times and 1.3 times of that in the day period respectively during spawning period, and about 1.5 times and 1.1 times during normal period. Overall, it is more reasonable and reliable to select the ten-day period as the calculating unit period,
and the runoff volume of it is adopted to analyse the instream ecological flow. So, the ecological flow ranges from 5.74 to 14.47 m$^3$/s during the spawning period, and 1.68~5.44 m$^3$/s during the normal period by the preliminary analysis.

4.3. **Instream ecological flow calculation based on section morphology analysis**

4.3.1. *The relationship between the water depth, flow and velocity.* The bottom elevation and the width of Shaduan section is about -2.47 m and 168 m, which is shallow-broad form. Besides, the Shifengxi river slope near the section is 1.4‰ (figure 3). According to the formula 1 and the measured section data, roughness and hydraulic gradient etc., the relationship curves between the water depth, flow and velocity of the section can be calculated (figure 4).

$$Q = AC\sqrt{RJ} \quad C = \frac{1}{n} R^{1/6} \quad V = Q/A \quad (1)$$

Where $Q$ is discharge volume (m$^3$/s); $h$ is the water depth (m); $V$ is the average flow rate (m/s); $A$ is the cross-section area (m$^2$); $R$ is the hydraulic radius; $J$ is the hydraulic gradient (m$^{-1}$), $C$ is the Chezy’s coefficient (m$^{1/2}$/s), and $n$ is the roughness.

By curve fitting method based on the power function, the relation equations between the water depth and discharge, the average velocity and discharge can be obtained respectively. The equations are as follows:

$$V=0.2787 \times Q^{0.2901} \quad (2)$$

$$h=0.1772 \times Q^{0.4671} \quad (3)$$

4.3.2. *The instream ecological water-depth and velocity.* Based on Zhangyuan and Yangyu’s papers [8,11], the minimum flow that can be sensed by fish inhabiting in the study basin is 0.2 m/s, and the appropriate velocity ranges from 0.3 m/s to 0.8 m/s. Because the water-depth for fish to survive should
not be less than 3 times of the fish length, the water-depth must be more than 0.3 m. Considering the different requirements of water-depth and flow rate of the fish during the spawning period and the normal period, it is proposed that the instream ecological flow rate is 0.3–0.8 m/s and the instream ecological water-depth is not less than 0.6 m during the spawning period, and not less than 0.2 m/s and 0.3 m during the normal period.

4.3.3. The instream ecological flow calculation. According to the ecological water-depth, the ecological flow rate and the relationship curves between the flow rate, water-depth and discharge, the instream ecological flow is figured out based on the hydraulic analysis (Formulas (2) and (3)), which is 13.61–37.90 m$^3$/s during the spawning period and 3.09 m$^3$/s during the normal period.

4.4. Instream ecological flow based on comprehensive analysis
By the hydrological analysis, the instream ecological flow of Shaduan section is figured out that is 5.74–14.47 m$^3$/s during the spawning period and 1.68–5.44 m$^3$/s during the normal period (table 2). By the hydraulic analysis, it turned out that the instream ecological flow is 13.61–37.90 m$^3$/s during the spawning period and 3.09 m$^3$/s during the normal period (table 2). By comprehensive comparison, it is concluded that the suitable instream ecological flow is 14.0 m$^3$/s during the spawning period and 3.1 m$^3$/s during the normal period.

| Methods                  | Ecological flow (m$^3$/s) | The spawning period | The normal period |
|--------------------------|---------------------------|---------------------|------------------|
| Hydrological analysis    | 5.74–14.47               | 1.68–5.44           |
| Hydraulic analysis       | 13.61–37.90              | 3.09                |
| Comprehensive analysis   | 14.0                     | 3.1                 |

5. Conclusion
The instream ecological flow is a fundamental work in water resource utilization, conservation and protection. This paper proposed an instream ecological flow calculation method based on hydrological analysis and channel morphology that not only considered the hydrological assurance rate, but also the habitat requirement of the aquatic organisms. Although this method couldn’t fully reflect the various ecological flow demand of the whole life cycle of aquatic organisms, it was able to overcome the scarceness of ecological monitoring data, requirement of long-time field observation, relatively large observational error and other problems, compared with the traditional habitat method and holistic method. In this paper, we selected Shaduan section of Shifengxi river located in Taizhou City, China as the study site, and divided the whole year into two calculating periods including the spawning period (from April to September) and the normal period (from October to March of the following year) in terms of the runoff temporal distribution and fish habit. Afterwards, the conclusion is that the recommended instream ecological flow is 14.0 m$^3$/s during the spawning period and 3.1 m$^3$/s during the normal period through comprehensive hydrological and hydraulic calculation and analysis.

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References
[1] Oxley R L, Mays L W and Murray A 2016 Optimization Model for the Sustainable Water Resource Management of River Basins. Water Resour. Manag. 30(9) 3247-64
[2] Liu J, Zhang Q and Xihui G U 2015 Evaluation of ecological flow with considerations of hydrological alterations in the Poyang Lake basin Acta Ecologica Sinica 2015 30-7
[3] Xu J, Xiao Y, Xie G et al 2019 Ecosystem service flow insights into horizontal ecological compensation standards for water resource: A case study in Dongjiang Lake Basin, China Chin. Geogr. Sci. 29 214-30
[4] Zhong P H and Liu H 2006 Review of assessment methods for instream ecological flow requirements Adv. Water Sci. 17 430-4
[5] Wang H X and Li M M 2019 Study on ecological flow of three estuaries of Jingjiang River in Yangtze River based on eco-hydrological method China Rural Water and Hydropower 2019 63-65+72
[6] Wu C H and Liu C M 2008 Study on calculation of ecological water consumption of channel by using ecological hydraulic radius Yellow River 2008 52-4
[7] Li M, Huang Q and Zhang H B 2007 Determination of ecological water demand based on necessary flow depth and velocity for specific ecological function J. Hydraul. Eng. 38 738-42
[8] Zhang Y and Zhao C S 2017 A method to calculate ecological flow base by coupling multi-species flow velocity requirement J. Beijing Normal Univ. (Nat. Sci.) 53 337-43
[9] Dong L X, Ye Y B and Gu Y 2018 Spatio-temporal analysis of ecological footprint and ecological carrying capacity of Taizhou water resources based on improved model Pearl River 39 116-23
[10] Qi H M, Xu Z L and Chen J J 2014 Analysis of temporal-spatial distribution of fish resources in the Taizhou Bay in spring and autumn J. Fish. China 38 1351-9
[11] Yang Y and Gao Y 2013 Advance of hydraulic tests concerning about fishes J. Hydroecol. 34 70-5