Ecological instream flow requirements calculation of Pihe River by Montana methodology in Sichuan basin China

W. Ouyang[1, 2] F.H. Hao[1] H. Chen[1] X.Wang[1] S.T. Yang[3]

1. School of Environment, State Key Laboratory of Water Environment Simulation, Beijing Normal University

2. International Institute for Geo-Information Science and Earth Observation (ITC), Netherlands

3. State Key Laboratory of Remote Sensing Science, Beijing Key Laboratory for Remote Sensing of Environment and Digital Cities, School of Geography, Beijing Normal University

Corresponding author: F.H. Hao, Tel/fax: 86 10 58807937.   E-mail address: fanghua@bnu.edu.cn

Abstract

With the rapid economic developments in China, the future water resource developments should be sustainable and that a component of the natural flow of rivers should be reserved to ensure diverse ecological functioning. In last 15 years, ecological instream flow requirements (EIFR) research of river was one of the main and hot fields for eco-hydrology scientists. In this paper, we summarized the research advance of eco-hydrology and also, the conception of the EIFR was also followed and calculated. The ecological instream flow has three main functions: maintain the water ecological environments, dilute pollutants and evaporate. To coordinate with the water resource allocation, we evaluated EIFR of Pihe River section in every 12 month of three typical years (1968, 1986 and 1987). Pihe River is one of the main water sources for the cities in Sichuan Basin and locates in the lower beach of famous Doujiang Weir. The Montana methodology was widely applied in water requirements estimate and proved usefully. Based on natural characters of Pihe River, minimum and optimum water requirement of aquatic habitat for the river maintenance were counted. Evaporation water requirement of Pihe River was computed too, which is related with the width of water surface, the river length and evaporation depth. Considering the water quality goal, diluting pollutant water requirement was taken into accounted. Then, the EIFR of the river of 12 month were ultimately ascertained. Among them, that was 20.64m^3/s and the minimum eco-environmental water requirement of the river was 25.84m^3/s.

Keywords Eco-environmental water requirements, Water resource allocation, Water quality goal, Pollutant dilute water requirement.

1 Introduction

The river water resource and allocation managements were based on the integrated factors of local economic developments, social status and environmental demands. The allocation of water to sustain natural ecosystems, to restore rivers degraded by over-abstraction and to protect biodiversity has become a key issue in water resource management in many countries (Gillilan and Brown, 1997). Since last century, there were much more attentions paid to economic developments and the water resource was over exploitive, which led runoff in lower beach was deprived (Stewart et al., 2006). The hydraulic engineering, which distributed over the rivers all over the world, was the most typical example (Wang et al., 2005).

The basic human needs reserve and the ecological needs are the core functions of water requirements. Quantifying the ecological reserve for rivers involves determining the water quantity and quality requirements that will ensure that they are sustained in a series of pre-determined conditions. These conditions can largely vary from natural to modify where there is a large loss of natural habitat, biota and basic ecosystem functions. How to establish in stream flow requirements is a component of the development of a new water resource management policy in China. Some rivers are environmentally important, but the requirements for socio-economic development in a water scarce region suggest that not all rivers can be retained in a near natural state. The water resource management should be sustainable and therefore all rivers should be protected to meet some basic ecological functions. Determining the quantity component of the ecological reserve is equivalent to set the water requirements for a given objective with respect to ecological maintenance. The ecological water requirements concepts allow the water resource to be managed for different purposes and that the deviation from natural in the level of ecological functioning will also vary. It has always been assumed that the total water requirements for a specific river will fluctuate as the ecological category changed and this assumption has been incorporated into the water resource managements. The factors that determine the EIFR of a river should include the site-specific ecological functioning. The relationships between flow and habitat are determined by the hydraulic characteristics of the channel and the hydrological regime characteristics. In this paper, we estimated the instream flow requirements for three major functions respectively.

2 The catchment area

The research area was located in Sichuan Basin, West of China. The famous and historical Dujiang Weirs was the base of water resource managements in the basin, where more than 80 million people lived over there. The Shidiyan Weirs was constructed in 1987 and controlled the water flow of Pihe River. At the Shidiyan Weirs, some parts of water flew to Fuhe River, which was the water source of Chengdu City, the capital city of Sichuan Province. Other parts flew to Pihe River, an important river in Chengdu plain. From Dujiang Weirs to Shidiyan Weirs, the river was named Baitiao River. From the Shidiyan Weirs to the Jintan village, where flow into Tuojiang River (a branch of Yangzi River), the length is 31 km. The whole length of two rivers is 64 km (Fig. 1). The Pihe River is a shallow river and the main function is irrigation in Dujianyan Weirs watershed. The width of winds River is 45～80m and the bank is 3～4m high. The water flow in Pihe River is determined by the remains of Shidiyan Weirs and the precipitations. At present, the water demand for domestic, agricultural and industrial uses climbed quickly in this watershed. More water is needed to be transferred for irrigation by the Goujiatan Weirs, so, it is necessary to estimate the eo-environmental requirement water of the lower reach. It is the base stone for water resource allocations.

Fig.1 Sketch map of Pihe River in Sichuan Province of China

The Shidiyan hydrological station was constructed in 1987, which dominated inflow quantity in Pihe River. After analysis of the water flow information from 1966～2000, we can find out that the 80.2% runoff of Pihe River happened from June to October. Another 7.7% occurred from December to April. The precipitation was the main source.

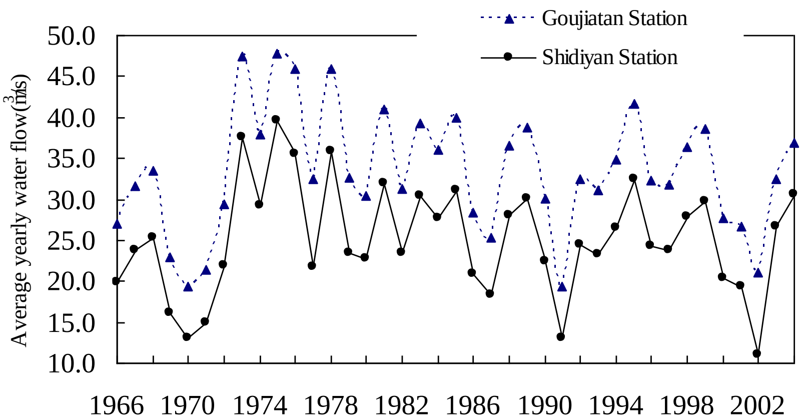

Fig.2 The average water flow in Shidiyan and Goujiatan sections from 1966 to 2004

The Goujiatan Weirs located in the middle of Pihe River, in Xindu County. However, there were only five year monitoring data (1975～1979) in this station. By the relations of water flow data on two stations in those five years, the water flow of Goujiatan hydrological station in other years can be estimated by the following equation.

$$Q=1.1483Q_0+4.3461 \qquad (1)$$

Where Q is the water flow in Goujiatan hydrological station; Q_0 is water flow in Shidiyan hydrological station.

The water flow fluctuation of Shidiyan and Goujiatan hydrological stations from 1966 to 2004 was demonstrated in Figure 2. Based on those 39 years data, the average water flow of Goujiatan station was 33.2m^3/s and the average yearly runoff was 1.048 billion m^3.

In Fig 3, the average flux of every twelve months from 1987 to 2000 was summarized. Apart in December, the water flow in Fuhe River was more than 35m^3/s. In dry season, after the adjustment of Shiduyan Weirs, the water flow (January to April) in Pihe River was so little, some periods less than 1m^3/s. In flood period, the water flow was more than 50m^3/s, occasionally more than 70m^3/s.

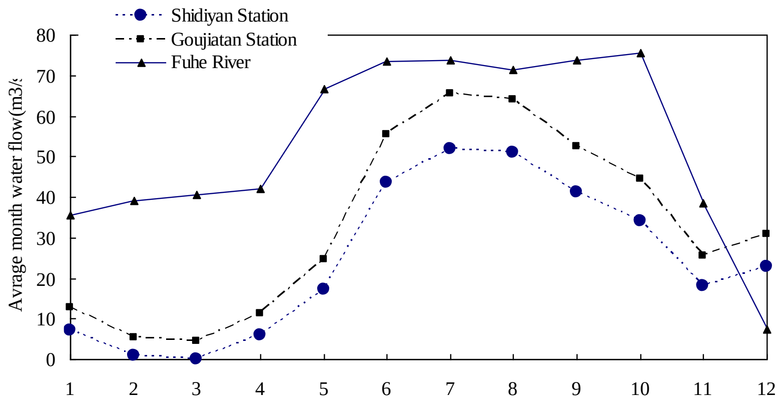

Fig.3 The average flux of 12 months in Shidiyan,Goujiatan and Fuhe sections from 1987 to 2000

Guided to the national water quality standard (GB3838-2002), the recent years' water quality between Baopingkou and Shidiyan section were good. The index of NH_3-N and BOD_5 was better than the third grade of national standard. According to monitoring data, the water quality of upper and lower section of Pihe River fluctuated seriously in flood and dry period. At present, the water resource in Pihe River has been exploited severely and the water quality has worsened to third or fifth grade at sometime. Occasionally, some sections were worse than fifth grade.

3 Methodology

Many different methods have been developed for determining ecological water requirements and there were some adapted method for inherent flow and habitat variability by several experts. The most popular methods were Montana, Wet Circle and R2CROSS (Mosely, 1982; Ubertini et al., 1996). In 1976, the Montana method was concluded out by Tennant, which was constituted by 8 grades and is a non-field monitoring methodology. The recommended river flow was predefined by the percentage of average yearly runoff.

There were more than 16 states in USA applied the Montana method to define the minimum water flow. The 10% of the yearly average water flow can maintain the water course stable. The 30% of average water flow can make the local ecosystem at optional state. The Tennant method was simple and conveniently to apply. Once the relationships between the water flow and ecosystem was set up, the estimation just need relatively little data. However, the Tennant method can just assess the minimum and the optional flow requirements, the water flow fluctuations can not be taken into accounted. So, more than thirty years' water flow monitoring information was necessary (Jackson et al., 2001). Pihe River was the low water level river and the major utility is irrigation. As the flood control river section, protection of aquatic vegetations is not the main functions. So, the application of the Montana method is reasonable.

From 1964 to 1974, Tennant carefully investigated 11 rivers in three states in American. The survey proved that 10%, 30% and 60% of average river flow were representative for the assessments of biological ecological suitable conditions (Thoms and Sheldon, 2002). The average river flow was changed in flood and dry time. The percent of water requirements in different water flow conditions were cited in Table 1 (Yang and Zhang, 2003).

Table1 Criterion of river flow to protect aquatic resource (percent of average river flow %)

Water flow	Average river flow in Oct~Mar	Average river flow in Apr~Sep
Maximum	200	200
Prime	60~100	60~100
Best	40	60
Better	30	50
Good	20	40
Middle	10	30
Minimum	10	10
Worst	0~10	0~10

4 Results and discussions

There are two principles should be followed during the analysis the EIFR. The first is that the water requirements should be allocated to meet some kind functions. The second was that the water flow in river may not be constant. The water flow in Pihe River fluctuated in all time, especially in the dry season and flood time. So, the EIFR and its threshold value should be calculated at different time. In this paper, we estimated the water requirements in each month under different assurance rate (Ni et al, 2002).

The EIFR should be a reasonable quantity with a threshold value. The minimum eco-environmental requirement water is the most lest needs of the local eco-systems. If the water flow was less than this value, the eco-systems will be destroyed or disappear. The optimum eco-environmental requirement water can make the eco-systems at good shape and develop well. Based on the major functions of Pihe River, the EIFR was summarized in following three parts, water requirements to protect aquatic resource, evaporation water requirement and diluting water requirement.

The EIFR should be harmonized with the water resource collocation in time. The experienced frequency distribution curve was concluded out by the water flow data at Goujiatan section from 1956 to 2004. With the hand of Person third frequency curve principle, the theory frequency distribution curve was educed (Fig 4).

After the analysis of the 49 years' water flow data at Goujiatan hydrological station, three typical years at different assurance rate (p) were selected for the calculations. There were 1968 (P=50%), 1986(P=75%), and 1987(P=90%). Follow the principle of Montana method for EIFR of river sections, the estimation of different condition were carried out.

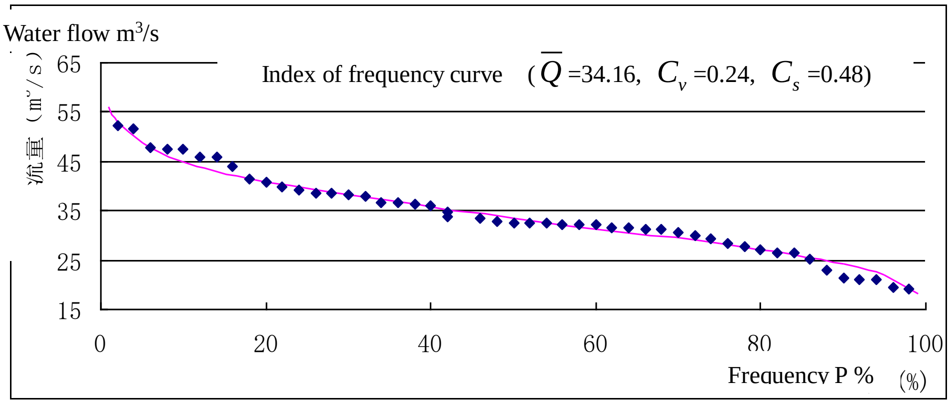

Fig.4 Discharge frequency curve of GouJiatan Station of Pihe River

4.1 Water requirements to protect aquatic resource

Based on the yearly runoff surveys of Pihe River, the flood period is from June to November and the dry season is from December to May. When calculate the river flow to protect aquatic resource by the Montana methodology, the minimum water requirement was set as the 10% of the average river flow of Pihe River. The optimum water requirement was 30% of the average river flow. In Table 2, the minimum and optimum water requirements of aquatic habitat in Goujiatan section of every 12 months in three typical years were demonstrated.

Table 2 The result of minimum and optimum water requirement of aquatic habitat from Goujiatan to estuary (m^3/s)

TY \ Month		1	2	3	4	5	6	7	8	9	10	11	12
P=50%	Min	1.17	0.78	0.51	0.82	4.34	3.64	3.73	8.55	8.32	6.27	1.16	0.70
(1968)	Opt	3.51	2.33	1.54	2.47	13.02	10.93	11.20	25.64	24.96	18.81	3.47	2.11
P=75%	Min	0.58	0.57	0.50	0.64	1.91	7.56	7.52	4.34	6.65	2.87	0.44	0.43
(1986)	Opt	1.73	1.70	1.50	1.92	5.72	22.69	22.56	13.02	19.96	8.62	1.31	1.30
P=90%	Min	0.43	0.43	0.43	0.52	1.12	6.53	6.29	4.65	5.93	2.68	0.67	0.67
(1987)	Opt	1.30	1.30	1.30	1.57	3.35	19.60	18.88	13.96	17.79	8.03	2.02	2.02

Note: TY was typical year; P was the assurance rate; Opt was the optimum water requirement and Min was minimum water requirement.

By the Montana method, the change of minimum water requirements to protect aquatic resource of different year changed obviously. At the assurance rate of 50%, the least water requirements were $0.51m^3/s$ and the biggest requirement was $8.55m^3/s$. At the assurance rate of 75%, the least requirement was $0.43m^3/s$ and the biggest requirement was $7.56m^3/s$. When the assurance rate was 90%, the least requirement decreased to $0.43m^3/s$ and biggest requirement was $6.53m^3/s$.

About the optimum water requirement, there were changed also. At the assurance rate of 50% in 1968, the least of water requirements was $1.54m^3/s$ and the biggest requirement was $25.64m^3/s$. At the assurance rate of 75%, the least requirement was $1.30m^3/s$ and the biggest requirement was $22.69m^3/s$. At the assurance rate of 90% in 1987, the least requirement was $1.30m^3/s$ and biggest requirement was $19.60m^3/s$.

4.2 Evaporation water requirement in river

It was critical for the evaporation water of river way to maintain the regional climate environment and other ecological functions of the river. The evaporation water was decided by the water width, average length between two sections on the simulated river and the evaporation depth in calculating period time.

$$Q_e = BLZ \qquad (2)$$

Where Q_e was evaporation water of river way; B was average width of river way (m); L was average length between two sections(m); Z was evaporation depth of river way in calculating period time(m). The more less of the river length, the simulation was the more accurate. The evaporation water requirement in Pihe River was accounted in Table 3.

Table 3 Evaporating water requirement for river course from Goujiatan to estuary (m^3/s)

Year \ Month	1	2	3	4	5	6	7	8	9	10	11	12
P=50% (1968)	0.027	0.018	0.012	0.019	0.099	0.083	0.085	0.194	0.189	0.143	0.026	0.016
P=75% (1986)	0.015	0.015	0.013	0.017	0.051	0.202	0.201	0.116	0.178	0.077	0.012	0.012
P=90% (1987)	0.013	0.013	0.013	0.016	0.033	0.196	0.188	0.139	0.178	0.080	0.020	0.020

After the calculation, the evaporation water requirement in lower reach of Goujiatan section was proved so little, which was the result of the little evaporation depth and river width. The evaporation water requirements in three typical years were less than 2.5million cubic meter. Due to the minor change of river width in these years, the evaporation water requirement did not change largely. So, the multiple years' average evaporation water requirement can present the evaporation water requirement of the river. At the 50% assurance rate, the evaporation water requirement of Pihe River was 0.0759m^3/s. At the 75% and 90%assurance rate, it increased to 0.0755m^3/s.

3.3 Diluting water requirement in river

For the special local eco-environment features and water functions, the water protection aim of these areas must be followed. The local governments have mapped out the protection guideline for water function. With the guideline for water function subarea of Sichuan Province, the water quality protection objective in lower reach of Goujiatan station was to keep water quality meet the national third grade at least. However, the water quality of this section was worse than third grade in the dry season and only met the guideline in flood season. So, the Shidiyan Weir was used to adjust the water flow to dilute the lower reach at the proper time. By the adjustments, the water quality in lower reach can meet the standard and the aquatic environments were protected.

After analyzed the water quality reports of Goujiatan section, Baopingkou section and Shidiyan section from 2003 to 2004, it can be concluded that the main pollutants index were NH_3-N and BOD_5. Because the diluting water requirement was just needed in the dry season (from January to April), the water requirement in dry season was calculated out by the following equation.

$$Q_x = \frac{(c_0 - c)Q}{c_0 - c_s} \tag{3}$$

Where, Q_x was dilute water flow (m^3/s); C was water quality of lower reach of Goujiatan section(mg/l); C_s was the water quality of national standard(mg/l); Q was water flow in lower reach of Goujiatan station (m^3/s); C_o was water quality of upper reach of Goujiatan station(mg/l).

Table 4 Pollutant diluting water requirement for river course from Goujiatan section to estuary in dry season (m^3/s)

Index \ Month	Jan	Feb	Mar	Apr
NH_3-N (In 2003)	20.39	21.27	20.39	20.39
BOD_5 (In 2003)	3.16	3.73	3.16	3.16
NH_3-N (In 2004)	20.48	51.28	20.48	20.48
BOD_5 (In 2004)	14.08	3.35	14.08	14.08

During the dry season, the water quality in Pihe River did not meet the guideline of water function. So, at that time, the diluting water requirement was critical for the water quality. The diluting water requirement of NH_3-N in February of 2004 was much bigger than in other months. However, the diluting water requirement of NH_3-N in other months in 2004 was same. In 2003, the diluting water requirement of NH_3-N in three months was also the same. So, the diluting water requirement of NH_3-N in dry season should be 20.39~20.48 m^3/s. Apart this four months, the water quality in May to December can meet the guideline for water function sub area and third grade of national water quality standard. It was not necessary to dilute the water. About water quality index, the NH_3-N was the most serious. Once this index met the needs, the others were also met.

3.4 Eco-environmental requirement water

For the multiple functions of water, it was difficult to define the EIFR quantity. The eco-environmental requirement water was overlapped with of water requirements to protect aquatic resource and dilute pollutants in same river reach. So, the EIFR was summation of the evaporation water requirement and the bigger one of the water requirements to protect aquatic resource and diluting water requirement. In this paper, we calculated the EIFR at the assurance rate of 50%, 75%, 90%, respectively. At different assurance rate, the minimum and optimum eco-environmental water requirements in twelve months of three typical years in lower reach of Goujiatan hydrological station were listed in Table 4.

Table 4 Minimum and optimum eco-environmental water requirements for river course from Goujiatan to estuary (m^3/s)

Month / TY		1	2	3	4	5	6	7	8	9	10	11	12
P=50%	Min	20.47	20.46	20.45	20.46	20.54	20.52	20.53	20.63	20.63	20.58	20.47	20.46
(1968)	Opt	20.47	20.46	20.45	20.46	20.54	20.52	20.53	25.84	25.51	20.58	20.47	20.46
P=75%	Min	20.46	20.46	20.45	20.46	20.49	20.64	20.64	20.56	20.62	20.52	20.46	20.46
(1986)	Opt	20.46	20.46	20.45	20.46	20.49	22.89	22.76	20.56	20.62	20.52	20.45	20.45
P=90%	Min	20.45	20.45	20.45	20.46	20.47	20.64	20.63	20.58	20.62	20.52	20.45	20.45
(1987)	Opt	20.45	20.45	20.45	20.46	20.47	20.64	20.63	20.58	20.62	20.52	20.46	20.46

Note: TY was typical year; P was the assurance rate; Opt was the optimum water requirement and Min was minimum water requirement.

After the estimation, at the different assurance rate (50%, 75% and 90%), the eco-environmental water requirements in the lower reach of Goujiatan hydrological station did not change obviously. The minimum EIFR were 20.45m^3/s and optimum was 20.64m^3/s. At the most of period, the eco-environmental water requirements of month in different year were same or just changed in 0.01 m^3/s.

5 Conclusions

The impact of human activities on ecosystem processes has long been of concerns of environmental researchers (Thoms and Sheldon, 2002). It is therefore appropriate that they are involved with water resources management decisions. The paper has attempted to summarize the hydrological data that are required for the different assurance rate of determination of the quantity component of the ecological instream flow requirements for rivers within China. While major of the ecological requirements approaches used in China have already been documented in the scientific literature. The water flow estimations played an important role within the intermediate and comprehensive determinations of water resource reallocations.

During estimating the ecological flow requirements, its social and environmental functions should be taken into accounted. At same time, the requirements were also changed by time. It is convenient to express the flow requirements in water flow. In these estimations, the minimum ecological flow requirements of Pihe River from Goujiatan station were 20.64m^3/s. The optimum ecological flow requirements were 25.84m^3/s.

The biggest limitation of the estimations was that some functional components may be ignored and be treated as ‘noise’. The limitation has to be noticed in the context of the variability of climate, topography and land cover, especially the large size of China.

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References

Denis A Hughes, Pauline Hannart, 2003. A desktop model used to provide an initial estimate of theecological instream flow requirements of rivers in South Africa, Journal of Hydrology, 270:167~181.

Donald Leroy Tennant, 1976. Instream Flow Regiments for Fish, Wildlife, Recreation and Related Environmental Resources[J]. Fisheries, 1(4): 6~10.

Geoffrey E. Petts, 1996. Water allocation to protect river ecosystems [J]. Regulated rivers: research & management. 12:353~365.

Gillilan DM, Brown TC., 1997. Instream Flow Protection: Seeking a Balance in Western Water Use. Island Press: Washington, DC.

Griphin R Symphorian a, E Madamombe, Pieter van der Zaag, 2003. Dam operation for environmental water releases; the case of Osborne dam, Save catchment, Zimbabwe[J]. Physics and Chemistry of the Earth, 28: 985~993.

Jackson RB, Carpenter SR, Dahm CN, et al., 2001. Water in a changing world. Ecological Applications, 11: 1027~1045.

Mosely. M. P., 1982. The effect of changing discharge on channel morphology and instream uses and in a braide river, Ohau River, New Zealand [J]. Water Resources Researches. 18: 800~812

Ni Jinren, Cui Shu bin, Li Tian hong, et al, 2002. On water demand of river ecosystem [J]. Journal of Hydraulic Engineering, 9: 18~19.

Stewart B. Rood, Chris George, Bobbi George, et al., 2006. Wilco Tymensen. Instream flows for recreation are closely correlated with mean discharge for rivers of western north america, river research and applications, 22: 91~108.

Thoms M C, Sheldon F, 2002. An ecosystem approach for determining environmental water allocations in Australian dryland river systems: the role of geomorphology. Geomorphology, 47:153~168.

Ubertini L, Manciola P, Casadei S., 1996. Evaluation of the minimum instream flow of the Tiber River basin [J]. Water Sa Wasadv, 41(2): 125~136.

Wang Liming, Hu Huijian, Wang Ding, 2005. Ecological impacts of disconnection from the Yangze on fish resources in Zhangdu Lake [J]. Resources and Environment in the Yangtze Basin, 3:158.

Yang Zhi feng, Zhang Yuan, 2003. Comparison of methods for ecological and environmental flow in river channels [J]. Journal of Hydrodynamics, 5(18):294~301.