

Study on Evaluation Index System of Reservoir Ecological Operation

Qidong Peng^{1,2}, Xingchen Gao¹, Dongdong Yan², Junqiang Lin², Tiantian Jin², Jiangbo Zhuang², Di Zhang² and Hao Xu²

¹Hubei Key Laboratory of Three Gorges Project for Conservation of Fishes, Chinese Sturgeon Research Institute, China Three Gorges Corporation, Yichang Hubei 443100;

²China Institute of Water Resources and Hydropower Research, Beijing 100038

Abstract—At present, the index of the effect evaluation of reservoir ecological operation cannot fully and systematically reflect the impact of the operation on the river ecosystem, and there is a lack of a complete and widely applicable index system. From the composition of river ecosystem, taking full account of the impact of water conservancy project on river ecosystem, this paper analyzes the effect of reservoir ecological operation from ecological environment benefit and social economic benefit, confirms the overall hierarchy of evaluation index system, and establishes the effect evaluation index system of reservoir ecological operation and the calculation method of each index. In this paper, the ecological operation of different objectives is analyzed, and evaluation indexes for water quantity, water quality, aquatic organisms and other operation objectives is established. The index system is applied to evaluate the ecological operation effect of four domestic fishes in Three Gorges reservoir. The results given in this paper are significance to the evaluation of reservoir ecological operation.

Keyword—ecological operation; index system; effect evaluation

I. RESEARCH BACKGROUND

For a long time, building reservoirs and storing water for the well-being of the people has been the main means of human development of river water resources. Although the construction and application of the reservoir achieve the goal of flood control and water use, it also changes the hydrological situation of the reservoir area and the downstream channel, resulting in local ecological environment and river health deterioration.

Reservoir operation inevitably has the impact on river eco-environment, the direct influence is the barrier effect of the dam and reservoir area inundation. The indirect influence is caused by the project change the original hydrologic process and hydrodynamic condition of the river. The ecological impacts of reservoir operation mainly include:

- (1) Impact on hydrology. The evolution of hydrologic situation are the most direct influences of reservoir operation and the core process of the influence of water engineering on the natural ecosystem. The variation of river flow and water level change the naturally seasonal variation pattern of river flow and eliminate the extreme changes of hydrology.

- (2) Impact on water quality. There are quite a few advantages, such as the slow water velocity in the reservoir caused by the barrier of the dam is conducive to the settlement of suspended matter and the reduction of water turbidity; There are also several disadvantages, such as excessive saturation of nitrogen and oxygen content in the water caused by high-speed outflow of the reservoir result in fish bubble disease^[1] and nutrient accumulation result in eutrophication of the reservoir area.
- (3) Impact on biological. Water conservancy projects damaged the necessary hydrologic conditions and growth environment for the growth and reproduction of aquatic organisms, especially fish. In addition, the inundation of the reservoir area leads to the death of the original vegetation and the decline of water level in the downstream river, and the destruction of farmland, forest and grassland vegetation.
- (4) Sediment deposition. After the construction of the water project, a large amount of sediment is trapped in the reservoir, causing the sediment deposit at the bottom of the reservoir. In addition, the slower water flow also changes the sediment content of the downstream channel and the riverbed topography.

Reservoir ecological operation aims to alleviate the ecological impact of reservoir, which has become a hot issue in the research of river ecological restoration of domestic and overseas^[2]. So far, many ecological operation have been studied in North America, Europe, Australia, Africa and China^[3-7].

Ecological operation is only a link to protect the ecological health of rivers. After the implementation of operation, it is necessary to evaluate the improvement effect of river ecology and develop improvement measures, so as to cyclic regulate the reservoir operation and ensure the health of river ecology. Foreign countries adopt adaptive management in the evaluation of ecological operation effect. They monitor and evaluate the impact of changing reservoir operation mode on ecological environmental objectives, and form a feedback mechanism for monitoring and evaluation, namely "adaptive management". However, they do not form a complete evaluation system and specific evaluation method for ecological operation effect^[6, 8]. C.P Konrad^[6] selected five types of hydrological indicators including invertebrate

diversity, water quality, water temperature, fish diversity, floodplains vegetation and IHA to monitor and evaluate the ecological target response results of Lin river, Savannah river and Bill Williams river. According to the 32 hydrological change indexes (IHA) of Yanshan reservoir, Wang et al. [9] determined the range of environmental flow using the Range of Variability Approach (RVA) based on the 32 indicators of hydrologic alteration (IHA) of Yanshan reservoir, and built the ecological operation model to simulate the daily water discharge process. In the range of environmental flow, 9 kinds of ecological scheduling schemes are proposed and evaluated, the evaluation indexes included the profit indexes (power generation and probability of water supply) and 5 groups of IHA hydrological indexes. Xu et al. [10] selected five first-level indicators, including ecological environment, resources and engineering technology, involving 22 second-level indicators, such as water quality, water temperature and economic development, to evaluate the ecological operation effect of the North Canal Dam using fuzzy comprehensive method, and the index weight and evaluation were assigned by experts, which was subjective.

From the point of the present study, both at home and abroad for ecological operation effect evaluation considering index is incomplete, have not form a comprehensive evaluation system and the specific evaluation methods. With the increasing attention of ecological and environmental benefits in reservoir operation, a complete set of evaluation index system is of crucial importance.

II. THE MAIN PURPOSE OF RESERVOIR ECOLOGICAL OPERATION

In order to alleviate ecological impact brought by water conservancy project construction, the main purpose of ecological operation is to improve the negative ecological impact of reservoir operation while ensuring economic and social benefits. The main purposes of ecological operation include:

- (1) Water quantity operation. Water quantity plays a leading role in water quality, velocity, water temperature, geomorphic change and other aspects of the basin.
- (2) Water quality operation. Ecological operation for water quality is mainly to control eutrophication, algal bloom and river pollution accidents. The mode of operation is to increase the discharge of reservoir.
- (3) Sediment operation. The aim of sediment ecological operation is to maintain the ecological health of the river by fully considering the water and sediment requirements of river geomorphology and river bottom organisms.
- (4) Aquatic organisms operation. Aquatic organisms operation refers to the operation to meet the growth and reproduction needs of aquatic organisms or to improve the biological population.
- (5) Ecological operation of other goals. In addition to the above mentioned ecological operation, reservoir ecological operation also includes operation for entertainment landscape, supplementing freshwater to

repulse saline water and other emergency operation with special objectives.

III. THE CONSTRUCTION OF THE EFFECT EVALUATION INDEX SYSTEM OF RESERVOIR ECOLOGICAL OPERATION

A. Index System Framework

The establishment of effect evaluation index system of reservoir ecological operation should first follow the principle of establishing evaluation index. Proceed from the ecological response of water conservancy projects, and refer to the thought of hierarchical analysis to deeply analyze the ecological operation of different goals, to set up evaluation index system, and to determine the overall hierarchical structure of evaluation index system. Generally speaking, the index system is divided into three levels: target level, criterion level and index level.

The target layer is to evaluate the ecological operation effect of the reservoir: to evaluate the overall effect of the reservoir operation on the new river ecological system and to better manage the reservoir operation.

The criterion level includes two aspects: eco-environmental benefits and social and economic benefits of ecological operation. Eco-environmental benefits can be evaluated from hydrological change, water quality improvement, aquatic population quantity and habitat improvement. The social and economic benefits mainly evaluate the impact of reservoir operation on flood control, power generation and water supply.

The index layer includes the first-level evaluation index corresponding to the criterion layer and the second level evaluation index under the first-level specific quantitative calculation and qualitative evaluation.

B. Index Selection and Basis

Based on consulting and analyzing relevant literature, the key influencing factors of each operation target are analyzed, and relevant indexes of reservoir ecological operation effect are summarized and selected. Each index is classified into 9 first-level indexes, and the second-level indexes are determined according to the principles of representativeness, scientificity and feasibility.

1) Ecological environment index

a) Hydrological

The hydrological index contains two aspects of water quantity and hydrological situation.

Water quantity plays a leading role in water quality, velocity, water temperature, geomorphic change and other aspects of the basin. Maintaining the ecological water demand is the key to meet the needs of river self-purification, maintain river channel state and the survival and reproduction of aquatic organisms. The main purpose of ecological water demand regulation is to meet the ecological water demand, such as groundwater replenishment, for the aquatic organisms survival and wetlands restoration, and to ensure the minimum water demand for maintaining the ecosystem stability. Based on the reliability of operation water source and the satisfaction rate of

operation to ecological water demand, the satisfaction rate of ecological flow was selected as the measurement index.

On the other hand, the hydrological process of rising and falling water affects the spawning and reproduction of aquatic organisms. For aquatic organisms, the process of rising is more important than the amount of water in many cases. The increase rate of water rising times, increase rate of water rising duration, initial flow increase rate of rising section and daily increase rate of flow are selected as the measurement indexes of hydrological situation.

b) The water quality

Eutrophication in the reservoir area is one of the major water environment problems faced by the lake and reservoir. The construction of water conservancy projects changes the hydrodynamic conditions, and the water purification conditions in reservoir areas become an important factor of eutrophication.

Nine indexes of surface water resource quality standard, including total phosphorus (TP), total nitrogen (TN) and water temperature, were selected from various factors affecting water quality in rivers and reservoir areas. The water temperature is an important factor affecting aquatic life. The construction of water conservancy projects can form stratification of water temperature in reservoir area, the water temperature stratification lead to the serious shortage of dissolved oxygen at the bottom of the reservoir, so as to the dissolved oxygen content of the reservoir outflow decreases sharply, and the zooplankton and benthic animals in the downstream channel are seriously affected. On the other hand, aquatic animal physiology and life habits in different seasons have different optimum temperature and adaptive variation of daily water temperature. However, the regulating effect of the reservoir weakens the seasonal change of water temperature in the downstream channel, which cannot provide the necessary temperature for quite a few aquatic organisms to complete their life cycle, and effect the breeding of aquatic organisms.

Water temperature stratification and low temperature water discharge affects river ecological security, so the variation value of the water temperature was selected as the second-level index for the evaluation of aquatic organisms. In addition, chloride content is the main index to evaluate the effect of salt treatment.

c) The sediment

At present, there are few reports on the relationship between reservoir sediment discharge and ecological environment of river channel. Swiss^[12], Bai Yinbaoliao^[13] et al., explored the impact of the Yellow River sediment discharge on fish and concluded that sediment concentration greater than 80kg/m³ would affect fish survival.

The reservoir sediment discharge solves the problem of sediment deposition in the reservoir area, and improves the river eco-environment to some extent. Meanwhile, the river sediment content affects the growth and reproduction of aquatic animals and plants, etc. Therefore, it is necessary to reduce the sediment content of the river and improve the

eco-environment through reservoir ecological operation. The increment of sediment discharge ratio and sediment load of downstream channel are selected as evaluation indexes of sediment operation.

d) Aquatic organisms

The decrease of water velocity caused by reservoir impoundment affects the community structure and population of the river and surrounding areas. The increase rate of biological resources and the increase rate of biodiversity index were selected as the evaluation indexes of aquatic organisms.

e) Habitat

Animals live in specific habitats. Habitat changes directly affect animal populations. Habitat suitability index (HSI)^[14] is an index to evaluate the suitability of biological habitats. The increment of habitat suitability index was selected as the habitat index to evaluate the operation effect.

2) Social and economic benefit index

a) Flood control

Flood control is one of the main objectives of the reservoir. The reservoir can effectively reduce the downstream flood level of the dam by regulating and storing flood. Meanwhile, the outflow of ecological operation should regard the downstream flood control safety as the prerequisite and guarantee, and the outflow should not be too large. The downstream flood control safety degree is selected as the flood control index.

b) Power generation

Part of reservoir capacity is used for ecological operation, reservoir capacity is an important factor affecting the power generation of a hydropower station. The loss of power generation is selected as the key evaluation index of the influence of ecological operation on power generation.

c) Water supply

Reservoirs, as the main carrier to regulate the uneven distribution of water resources, shoulder the important task of promoting profits. Urban water supply varies with different water users, so does the guarantee degree of water supply. The guarantee rate of urban water supply and the guarantee rate of irrigation water supply were selected as water supply indicators.

d) Landscape

Reservoir ecological operation can improve river ecological landscape to some extent. The river ecosystem landscape is unique, and it has the recreation function. The combination of forest and grassland landscape in the upper reaches of the river with lake beach and wetland landscape in the lower reaches makes the landscape diversity obvious, and the dynamic and static echoes of flowing water and river bank, fish and birds, forest and grass constitute the harmony and unity of river landscape. Therefore, people take advantage of the landscape leisure service function of watershed ecosystem to carry out leisure activities during the holidays. Landscape comfort improvement and public satisfaction are selected as evaluation indexes.

C. Index System and Calculation Basis

According to the above index system framework, the evaluation index system and calculation basis of specific reservoir ecological operation effect are shown in table 1.

The increase rate of water rising times, increase rate of water rising duration, initial flow increase rate of rising section and daily increase rate of flow are selected as the measurement indexes of hydrological situation.

TABLE I. EVALUATION INDEX SYSTEM OF RESERVOIR ECOLOGICAL OPERATION EFFECT AND CALCULATION BASIS

Target layer	Rule layer	First-level index	Second-level index	Calculation basis
Ecological operation effect of reservoir	Ecological And environmental benefits	Hydrological	Ecological water demand satisfaction rate	The number of days when the critical life period flow of the target organism reaches the ecological water demand flow/the total duration days of the operation; The minimum ecological flow value can be calculated according to the improved 7Q10 method (dry water frequency method) ^[15]
			Increment of times of water rises	The number of water rises in the operation period - the annual average number of water rises in the same period (it is defined that the continuous water rises for more than 2 days are a water rising process)
			Increment of water rising duration	Duration of surge in operation period - the annual average duration of water rises in the same period
			Initial flow increase rate of water rising section	(rising section initial flow in operation period - rising section initial flow in years of same period) × 100% / rising section initial flow in years of same period
			Percentage increase of daily growth rate of flow	(daily growth rate of flow in operation period - daily growth rate of annual average flow in the same period) × 100% / initial flow rate of annual average rising section in the same period
			Water temperature of outflow	With reference to the method given in Environmental Quality Standard for Surface Water, the content of each water quality index is determined and the difference before and after operation is calculated.
		The water quality	Dissolved oxygen content	With reference to the method given in Environmental Quality Standard for Surface Water, the content of each water quality index is determined and the difference before and after operation is calculated.
			Reduced value of total phosphorus	
			Reduced value of total nitrogen	
			Reduced value of Permanganate index	
			Chemical oxygen demand decreases	
			Biochemical oxygen demand decreases	
			Reduced value of ammonia nitrogen	
			Variation of PH	
	Aquatic organisms	Increment of biodiversity index	Reduced value of Chloride content	Shannon-wiener diversity index method was adopted to calculate ^[16] . Sampling survey was conducted to calculate the amount of biological resources before and after operation.
			Increment of biological resources	
		habitat	Improvement of habit	
	Sediment delivery	Increment of reservoir sediment delivery rate	Improvement of ecological landscape comfort level	Calculation based on habitat suitability index (HSI) model ^[17]
			Downstream sediment load	Reservoir sediment delivery rate = the amount of outflow sediment /the amount of inflow sediment, and the difference of reservoir sediment delivery rate of before and after operation is calculated
	Socio-economic benefit	Flood control	Safety of downstream flood control	The number of days when the discharge rate is greater than the safe discharge rate × 100% / the total days of the operation period
		Power generation	Loss of power generation	P = 9.81ηQH, (P is the power generation loss, Q is daily water, η is turbine power generation efficiency coefficient, H is productive head)
		The water supply	Urban water supply guarantee rate	Guarantee rate of urban water supply = actual water supply × 100% / urban water demand
			Irrigation water supply guarantee rate	Irrigation water supply guarantee rate = actual water supply × 100% / irrigation water demand
		landscape	Improvement of ecological landscape comfort level	Qualitative index, field investigation and expert evaluation
			Public satisfaction	Qualitative index, questionnaire survey

D. Selection of Evaluation Indexes for Different Scheduling Objectives

Considering different operation objectives, the decisive indexes that affect the operation effect are not the same. For water quantity operation, water quality operation, sediment operation, aquatic biological operation, saltwater suppression operation and other objectives (landscape operation, etc.), different key indexes can be selected. For water quantity operation, hydrological index, such as the satisfaction rate of ecological water demand, increase rate of times of water rises, increase rate of water rising duration, the increase percentage of rising section initial flow, the increase percentage of the daily growth rate of flow, and social and economic benefit index such as safety of downstream flood control, loss of power generation, the guarantee rate of urban water supply, the guarantee rate of irrigation water supply, public satisfaction, etc., can be selected. For water quality operation, water quality index such as improvement of dissolved oxygen, variation of outflow temperature, total phosphorus decreases, total nitrogen decreases, permanganate index decreases, chemical oxygen demand decreases, biochemical oxygen demand decreases, the reduced value of ammonia nitrogen, variation of pH and various social and economic benefit indexes can be selected. For sediment operation, the increment of reservoir sediment delivery rate, improvement degree of sediment content in downstream channels and various social and economic benefit indexes can be selected. For hydrobiotic operation, you can focus on water quantity and water quantity indexes closely related to aquatic life, and aquatic and habitat indexes such as the increment of biodiversity index, the increment of biological resources, improvement of habitat, etc.

E. Ecological Operation Effect Evaluation Index Measurement Standard

In the process of evaluating the reservoir ecological operation effect, the indexes in the index system are divided into quantitative and qualitative indexes. The quantitative indexes of the evaluation criteria refer to the calculation basis in table 1 and reference to relevant literature standards.

According to the scheduling effect of each index, it can be divided into five grades: excellent, good, medium, poor and bad. The corresponding scores are: excellent (80-100), good (60-80), medium (40-60), poor (20-40) and bad (0-20).

IV. EVALUATION OF ECOLOGICAL OPERATION EFFECT OF THREE GORGES RESERVOIR

A. Overview of Ecological Operation of Three Gorges Reservoir

During the design of the Three Gorges project, the possible impact of the project operation on the ecological environment has been analyzed^[18], and the impact of the Three Gorges project on the ecological environment mainly includes the water temperature, water quality, aquatic organisms and the invasion of salty tides in the reservoir area and downstream.

Four domestic fishes is a typical species adapted to the ecosystem of the middle and lower reaches of the Yangtze river, and also a species greatly affected by the operation of the

Three Gorges reservoir^[19]. The research showed that the breeding activity of four domestic fishes is usually from May to June. The main factors affecting the spawning of four domestic fishes are the number of parent fish, water temperature, hydrologic condition and spawning ground, etc.^[20] Among them, water temperature is one of the main external conditions affecting the breeding of four species. The minimum water temperature for four domestic fishes operation breeding is 18°C. According to the investigation, four domestic fishes operation start to lay eggs at about 0.5 ~ 2d after the river rises. The average daily flood rate ranges from 0.12 to 0.36 m/d. The duration of spawning is over 4d, and the average duration is 11d, ranging from 4 to 18d^[19]. The operation of the Three Gorges project has changed the hydraulic characteristics of four domestic fishes operation spawning grounds, which has certain influences on the spawning reproduction and scale of four domestic fishes operation^[21]. According to the results of monitoring the runoff of fish larvae in the Jianli section, the spawning scale in the Jianli section decreased obviously before and after the impoundment of the Three Gorges reservoir. Relevant studies have shown that there is a direct relationship between the spawning scale of four domestic fishes operation and the process of river water level rising^[22].

From 2011 to 2018, 12 ecological operation experiments were carried out for eight consecutive years to promote the spawning of four domestic fishes. Under the appropriate water temperature condition, based on the inflow condition of the Three Gorges reservoir, the process of outflow is changed to artificially create the hydrologic conditions and hydraulics conditions (flood peak process) suitable for spawning of four domestic fishes.

The monitoring data prove that the ecological operation plays a positive role in the increase of early resources of four domestic fishes operation in Yichang to Jianli river section: from 2011 to 2017, the total egg number of four domestic fishes was 4.5 million, 610 million, 116 million, 161 million, 326 million, 502 million and 144.8 million, respectively; the egg number of four domestic fishes during ecological operation was 1 million, 406 million, 58 million, 54 million, 104 million, 2.4 million and 86.8 million, respectively. The total egg number of four domestic fishes in 10 ecological operation experiments was 712.2 million, accounting for 38.2% of the total egg number in 7 years.

B. Index Selection and Weighting

Refer to table 1 and 2, the key evaluation index for the Three Gorges reservoir ecological operation are selected. There are 3 first-level indicators and 7 second-level indicators. The criteria layer of eco-environmental benefits includes four hydrological indicators (Increment of water rising duration, Increase percentage of initial flow increase rate of water rising section, Increase percentage of daily growth rate of flow, water temperature), two water quality indicators (the improvement of dissolved oxygen, pH value), and one aquatic biological indicator, the increment of biological resources.

The weight value of each indicator depends on the importance of the index relative to the overall target. For the ecological operation of the Three Gorges reservoir, the main purpose is to promote the spawning of four domestic fishes. Therefore, the eco-environmental benefits are the primary goal. Comparing the three first-level indicators of eco-environmental benefits, the importance of aquatic indicators is significantly

higher than that of hydrological indicators and water quality indicators.

Objective weight coefficient of each index and sub-target is determined by analytic hierarchy process [23-24], and 1-9 scale method is used to assign weight to each layer of index. The weighting results are shown in table 2.

TABLE II. THREE GORGES RESERVOIR ECOLOGICAL OPERATION EFFECT EVALUATION INDEX WEIGHT TABLE

Target layer	Rule layer	Weight	Index layer			Single weight	Total weight
			First-level index		Second-level indicators		
Reservoir ecological operation effect A1	Ecological and environmental benefits B1	1	Hydrological C1	0.2790	Increment of duration of rising D1	0.3519	0.0982
					Increase percentage of rising section initial flow D2	0.0495	0.0138
					Increase percentage of the daily growth rate of rising D3	0.1016	0.0283
					Water temperature D4	0.4971	0.1387
			Water quality C2	0.0719	Dissolved oxygen D5	0.75	0.0539
					pH D6	0.25	0.0180
			Aquatic organisms C3	0.6491	Incremnet of Biological resources D7	1	0.6491

C. Comprehensive Evaluation Result

With reference to the above, the ecological operation effect of the Three Gorges reservoir is systematically evaluated. First, each evaluation index value in the comprehensive evaluation is determined. Second, it is necessary to determine the single factor evaluation membership vector to form the membership matrix. Finally, the comprehensive evaluation is given.

1) Determine the fuzzy comprehensive evaluation factor set

The first layer is the factor set of criterion layer

$$U=\{u_1, u_2\}=\{\text{Ecological and environmental benefits, social and economic benefits}\}$$

$$U_1=\{u_{11}, u_{12}, u_{13}\}=\{\text{hydrological, water quality, aquatic organisms}\}$$

$$U_2=\{u_{21}\}=\{\text{power generation}\}$$

2) Establish a rating level

First of all, according to the eight factors in the above-mentioned indicator factor set, the evaluation subject makes an evaluation on the evaluation object. Comments = {excellent (V1), good (V2), medium (V3), poor (V4), bad (V5)} = {80, 60, 40, 20, 0}

3) Construct the membership degree matrix

Combined with the evaluation criteria of each indicator in Table 2, the fuzzy evaluation matrix of indicator factor set to comment set is calculated.

TABLE III. THREE GORGES RESERVOIR ECOLOGICAL OPERATION EFFECT SCORE

Index	2013			2014			2016		
	The numerical	Evaluation	Score	The numerical	Evaluation	Score	The numerical	Evaluation	Score
Incremnet of duration of rising (d)	5.8	excellent	98	-0.5	poor (-1~0)	30	-0.2	poor (-1~0)	35
Increase percentage of rising section initial flow	-5.10%	Poor (-25%~0)	32	81.30%	excellent ($\geq 25\%$)	98	76.50%	excellent ($\geq 25\%$)	90
The increase percentage of the daily growth rate of flow	-45.80%	bad ($\leq -25\%$)	15	-15.90%	bad (-25%~0)	32	51.20%	excellent ($\geq 25\%$)	88
Outflow temperature (°C)	18.9	good	75	19.2	good	82	18.6	excellent	86
Dissolved oxygen (mg/L)	8.24	excellent	85	8.47	excellent	89	7.12	excellent	100
pH	6.8	good	79	7.42	excellent	100	6.4	good	78
Increment of biological resources (million)	58	excellent	82	54	excellent	81	2.4	medium	48

According to the above table, the total evaluation results Z of three different years can be calculated, and the comprehensive evaluation is: $Z=R \times W$.

In 2013:

$$Z=R_{all} \times W_{all} = (98, 32, 15, 75, 85, 79, 82) \\ (0.0982, 0.0138, 0.0283, 0.1387, 0.0539, 0.0180, 0.6491)^T = 80.12$$

For 2013, the comprehensive score of ecological operation effect is 80.12 (100 points in total), and the effect was good and in the state of "excellent". During the ecological operation

of the Three Gorges reservoir in 2013, the number of days with rising water is 10, the egg number of fish is 58 million, the discharge meets the Three Gorges reservoir safety discharge standard of $43000m^3/s$, the water quality index are in the " excellent " or "good" state. Therefore, in 2013, the ecological operation effect of Three Gorges reservoir is good, the experiences worthy to be referenced for the future ecological operation work.

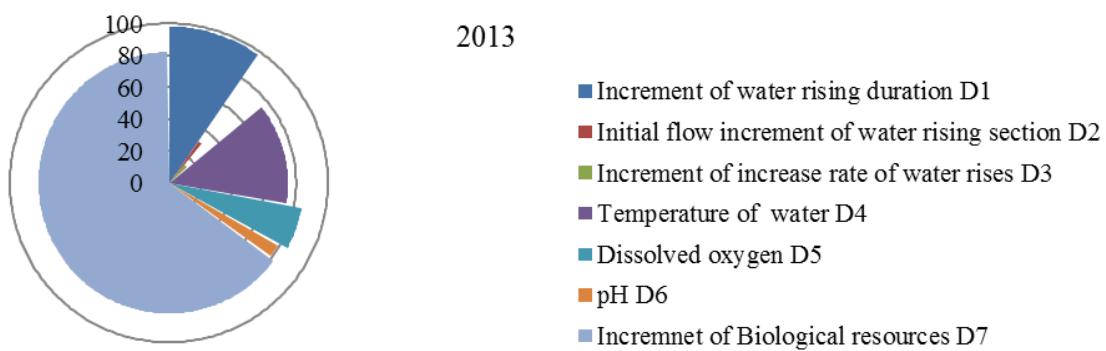


FIGURE I. THREE GORGES RESERVOIR ECOLOGICAL OPERATION EFFECT IN 2013

In 2014:

$$Z=R_{all} \times W_{all} = (30, 98, 32, 82, 89, 100, 81) \\ (0.0982, 0.0138, 0.0283, 0.1387, 0.0539, 0.0180, 0.6491)^T = 75.75$$

For 2014, the comprehensive score of ecological operation effect is 75.75 (100 points in total), and in the state of "good". During the ecological operation of the Three Gorges reservoir

in 2014, the number of days with rising water is 4, the egg number of fish is 54 million, the discharge meets the Three Gorges reservoir safety discharge standard of $43000m^3/s$, the water quality index is also in the " excellent " or "good" state ,and the initial flow is up to $15500 m^3/s$. Therefore, in 2014, the ecological operation effect of Three Gorges reservoir is good.

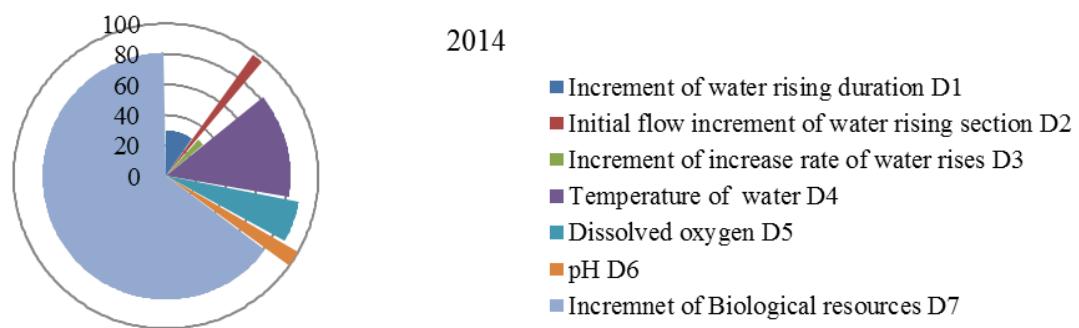


FIGURE II. THREE GORGES RESERVOIR ECOLOGICAL OPERATION EFFECT IN 2014

In 2016:

$$Z=R_{all} \times W_{all} = (35, 90, 88, 86, 100, 78, 48) \\ (0.0982, 0.0138, 0.0283, 0.1387, 0.0539, 0.0180, 0.6491)^T = 57.05$$

For 2016, the comprehensive score of ecological operation effect is 57.05 (100 points in total), and the effect was good

and in the state of "medium". The egg number of fish was 2.4 million, which was lower than that in previous years, and there will be still much room for improvement. The discharge meets the Three Gorges reservoir safety discharge standard of $43000 m^3/s$ during the operation period. The reason for the relatively few egg number of fish in 2016 may be water quality or other objective factors.

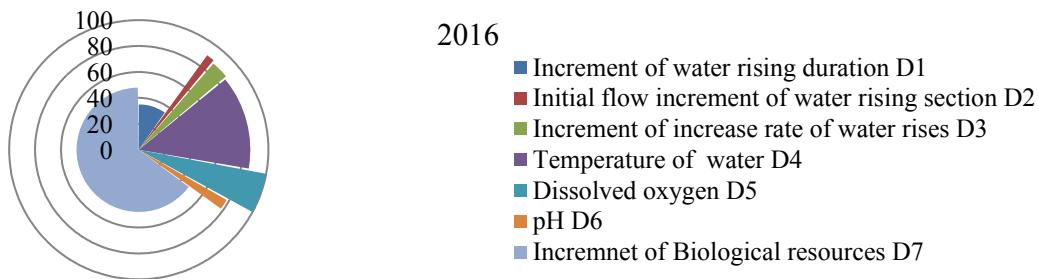


FIGURE III. THREE GORGES RESERVOIR ECOLOGICAL OPERATION EFFECT IN 2016

V. CONCLUSION

On the basis of fully considering the effect of water conservancy project on river ecosystem and the main purpose of reservoir ecological operation, this paper develops an ecological operation evaluation index system. Based on the analysis for ecological operation objectives, a three-layer evaluation index system of ecological operation including two criterion of eco-environmental benefits, social and economic benefits, 9 first-level indexes and 26 second-level indexes is constructed. On this basis, the Three Gorges as an example to verify the practical application of the index system. According to the main objective of Three Gorges reservoir ecological operation, the evaluation indexes are selected reasonably, and the ecological operation effect of Three Gorges reservoir for four domestic fishes is evaluated.

As an important part of reservoir management and operation, the effect evaluation index system of reservoir ecological operation involves many factors. The weight of evaluation index and evaluation standard of different operation objectives vary greatly. How to establish an objective and unified evaluation standard needs to be further studied.

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