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Characteristics and Practices of Ecological Flow in Rivers with Flow Reductions Due to Water Storage and Hydropower Projects in China

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Abstract: Water and flow reductions in the channels downstream of water storage and hydropower projects have significant impacts on aquatic ecosystems. Understanding and analyzing the ecosystem status is of great significance to facilitate the protection of riverine ecosystems. A database was established based on the 2000–2017 environmental impact assessment (EIA) reports on water storage and hydropower projects in China, and corresponding analysis software was built based on an ArcGIS spatial analysis platform. The projects in China are mainly found in the Yangtze and Pearl River basins and in south-western China. The hydropower projects have a larger influence than the water storage projects on the flow of downstream rivers sections, and most of the hydropower projects, especially the water diversion projects, cause flow reductions in the downstream rivers. An ecological flow management mechanism in China implemented in 2006 provided a promising method to alleviate river flow reductions. However, there is still only one kind of ecological flow calculation method and few ecological flow regulation measures in use. Based on the advantages and problems of the existing ecological flow management system, this paper proposes a management scheme based on a regional-engineering calculation method. The results can facilitate decision making in ecological flow management.

Keywords: ecological flow; flow reductions; water storage and hydropower projects; management

1. Introduction

River ecosystems result from a dynamic balance between the biotic (e.g., plants and animals) and abiotic (e.g., climate, topography, and hydrology) factors under natural flow. The construction and operation of water storage and hydropower projects have changed the hydrology of rivers leading to changes in riverine ecosystems. China is one of the largest countries in terms of water storage and hydropower development, and there are already approximately 100,000 reservoirs in existing rivers according to incomplete statistics. The construction of these projects has had substantial impacts on river ecosystems [1–3]. Research on the hydrological changes in 186 rivers that were built in the United States indicated that the water storage and hydropower projects in rivers with dams lead to homogenization of species composition and have had negative impacts on native fish diversity [4,5].

Moreover, the most significant hydrological variability factors caused by reservoirs were the change of hydrology from natural flow to artificial flow, and the flow always tends to homogenization [6–8]. Sagawa and co-authors attempted to determine the relationships between the hydrology and fish diversity and species abundance by identifying the hydrological indicators that had significant impacts on fish communities [9–11]. In addition, it is now globally understood that one of the major impacts of water storage and hydropower projects on downstream river ecosystems is the occurrence of flow reduction [12,13].

The concept of ecological flow is not yet clear, and generally refers to a flow process that maintains the health of rivers and estuaries and meets the needs of human life, including water quantity, water quality and duration. Considering that ecosystem health is the highest goal of river health, the ecosystem protection goal is the minimum requirement for the minimum flow of the river [14]. It is considered the main technical approach to balance the utilization of water resources and the water ecosystem, and also one of the most effective measures for hydrological restoration [15]. The ecological analysis of the current situations of downstream projects is significant for the ecological restoration of rivers, especially when reducing river flow reductions. The variations in ecological systems are based on ecological flow; however, ecological management should be a dynamic process which needs to make corresponding management changes according to the change of downstream ecosystem.

Extensive relevant research and applications have taken place throughout the world, and significant experience has been obtained. The United States Fish and Wildlife Service (FWS) had successfully applied adaptive management to the Glen Canyon Dam to maintain the stability of the downstream ecosystem [16]. A comprehensive restoration plan for wetlands in Florida adopted the adaptive management concept, and this plan aims to improve water quality and restore deteriorated hydrological conditions to achieve the coordinated development of human progress and protection of the ecological environment. Adaptive management is also utilized for the management of Mississippi River flow, and the management plan has proposed gradual change. At present, the United States has applied adaptive management to the integrated management of river ecology, navigation, landscape and entertainment in the upper Mississippi River; the ecological restoration of wetlands in Florida; the ecological restoration of wetlands along the Louisiana coast; and the coordinated development of salmon protection and hydroelectric power generation in the Columbia River in Washington State [17,18]. Other countries are also actively researching and applying adaptive management. The Canadian Environmental Assessment Agency, for example, has proposed adaptive management proposals for complex ecosystems.

Adaptive management in China started late, but can be considered a key factor to ensure the success of river ecological restoration projects [19]. Xia J and co-authors applied adaptive management of water resources and drinking water source management in the Miyun Reservoir, and adaptive management also has been introduced to the water resources management of the Yellow River Delta [20]. Adaptive management, including the monitoring, evaluation and coordination of various stakeholders was proposed in the Three Gorges Reservoir to maximize the benefits of the reservoir [21]. Overall, scholars in China argue that adaptive management is a necessarily complex solution to the complex issues associated with river ecological protection. This concept is also considered an effective solution to problems associated with the reproduction of aquatic organisms. Government authorities have applied adaptive management to the practice of ecological flow management since 2000. Over the past 15 years, the government has issued a series of policies to ensure the effectiveness and optimization of water release with the aim of guaranteeing ecological flow. In 2006, the 'Technical Guide for Environmental Impact Assessment of River Ecological Flow, Cold Water, and Fish Passage Facilities for Water Conservation Construction Projects (Trial) EIA Letter [2006] No.4' was issued by the State Environmental Protection Administration. In this document, a rule that identified an annual average flow of 10% as the ecological base flow was first defined as the minimum flow standard for water storage and hydropower projects in China. In the case of the protection of sensitive downstream targets, the flow duration curve was considered to be a standard measure of the flow. However, some problems remain in the above management system [22,23]. Thus, we need to gradually improve the management system according to the principle of adaptive management.

Therefore, 10 years after the practice of ecological flow management was introduced in China, we collected 206 EIA reports from 2000 to 2017 and analysed spatial and temporal distribution of water storage and hydropower projects, and the impacts on the downstream rivers. The existing ecological flow management practices have also been discussed in this paper, and give new ideas for ecological management. The research results can provide inform and help prioritize the restoration of river ecosystems, the improvement of the ecological environment of a river basin and the evaluation of water resource security.

2. Materials and Methods

2.1. Database

We constructed a database to include the basic information, ecological characteristics and ecological flow management measures of water storage and hydropower projects in China from 2000 to 2017. The analysed projects had passed the EIAs, which were downloaded from the EIA report database of the Ministry of Environmental Protection. During the EIA, expert opinions were a significant factors used to quantitatively determine and optimize the ecological flow, and the contents of the EIA report represent the suggestions of China's experts and government departments specializing on environmental impacts.

All projects were imported into a SQL Server database, and could be collected by the software. Therefore, we could show and edit the data on a map using the software.

2.2. Analysis Software

The decision-making of ecological flow management needs to consider multidisciplinary, multifaceted materials and should compare multiple schemes. Considering these processes are often tedious and complex, we have developed an ecological flow decision assistant software.

The software was based on a Windows platform using the Visual Basic. NET programming tool, the ArcGIS engine platform (version 9.3, EsriChina, Beijing, China), and the SQL Server database, which provide a computing and analysing platform with data visualization, a friendly interface, and simple operation. The software copyright was obtained from the National Copyright Administration in China (registration number: 1714997).

One of the main functions of the software consisted of information processing which was used to conduct spatial information queries and computer statistics. Based on spatial topography technology, we analysed and mapped the spatial and temporal distributions of water storage and hydropower projects (Figure 1).

We counted the water storage and hydropower projects that caused flow reductions in downstream rivers using the software, and the implementation, safeguards and monitoring measures for ecological flow were identified. We also analysed the impacts of the characteristics of water storage and hydropower projects to the flow reduction in downstream rivers, and the management measures utilized were analysed.

2.3. Caculation Method of Ecological Flow

An ecological flow management decision is difficult due to the uncertainty regarding how to quantify the ecological base flow. At present, the relevant calculation methods are relatively matched and there are about more than 200 kinds of methods in the world that can be divided into the hydrological, hydraulic, physical habitat and comprehensive methods.

The hydrological method is the most commonly used method to calculate river ecological base flow in the world, which uses simple hydrological indicators to set the flow. The result is usually a single flow, and a commonly used method is the Tennant method [24]. The hydraulic method uses the

Manning equation to establish the relationship between ecological flow and hydraulic factors, and the commonly used method is the R2Cross method [25]. The physical habitat method is an improved vision of the hydraulic method, and determines the ecological base flow by establishing the relationship between the environmental factors of protected species habitat, the hydraulic and flow conditions, and the commonly used method is the ecological hydrodynamic method [26]. This comprehensive method emphasizes the river is an integrated ecosystem. Based on experts' opinion, the recommended river flow is set to meet the demands of e.g., biological protection, habitat maintenance, sediment deposition, pollution control and landscape maintenance. However, this method requires a lot of ecological data, and the evaluation takes a long time, which limits its application [27].

Due to the multiple types of methods, this paper reviews the methods used in the projects that were implemented after 2006 which caused flow reduction, and determines the current situation and problems of various methods in China.

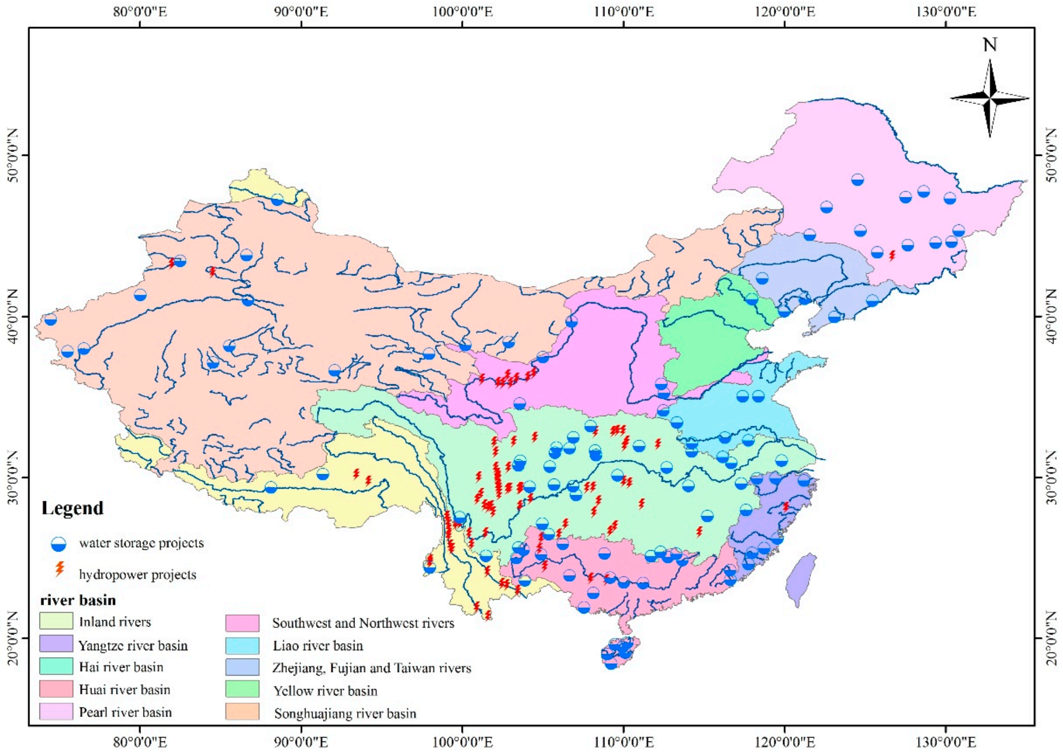


Figure 1. Locations of the water storage and hydropower projects.

3. Results

3.1. Temporal and Spatial Distributions

A total of 206 water storage and hydropower projects were collected, and 75 of these were established from 2000–2005, which included 37 water storage projects and 38 hydropower projects; 131 projects were implemented after 2006, which included 75 water storage projects and 56 hydropower projects (Figure 2a).

All water regulation structures were distributed in different basins, and a total of 86 of the above projects were in the Yangtze River basin, while the Pearl River basin and the South-west and North-western rivers harboured 29 and 26 of the total projects, respectively. The Yellow River basin, the Songhua River basin and the inland River basin harboured 13, 17 and 12 of the above projects, respectively (Figure 2b).

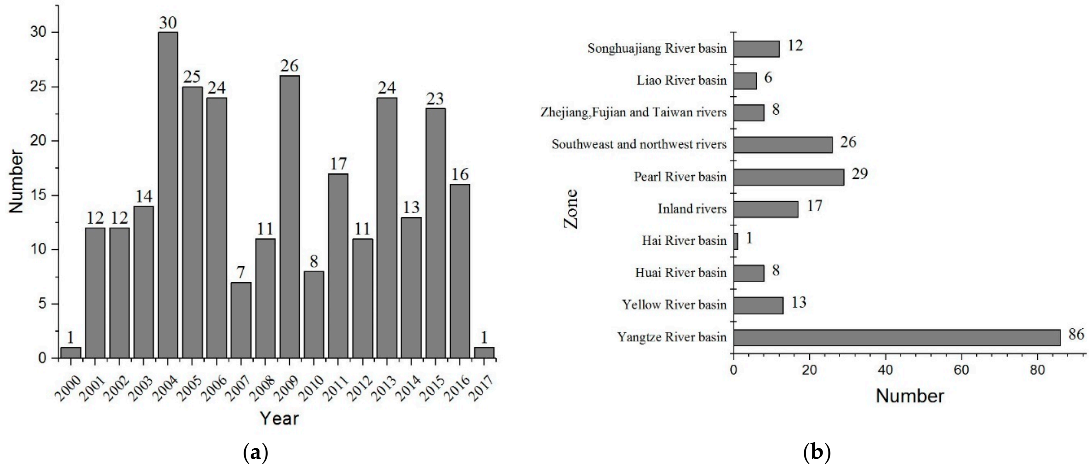


Figure 2. (**a**) Temporal distributions of water storage and hydropower projects; (**b**) spatial distributions of water storage and hydropower projects.

3.2. Functional Difference Statistics

The water storage and hydropower projects can be divided into various types. Regarding the project types, they can be divided into dam, diversion and mixed types, and they can also be divided into 7 additional types according to their capacity of regulation, such as over a year, annual, incomplete annual, seasonal, weekly, daily and no regulation.

3.2.1. Construct Types

We summarized the relationship between the construction process type and the flow reduction events in the downstream river.

Among the 206 projects, 100 are dam projects, 23 were diversion projects, 16 are mixed projects, and 67 were undefined projects in the EIA report on water storage and hydropower projects (Table 1).

Regarding the regulation capacity, 67 projects utilized daily regulation, 79 utilized annual, semi-annual or multi-year regulation, 18 utilized weekly or seasonal regulation, and 42 had no regulation capacity (Table 1).

Table 1. Functional statistics of the water storage and hydropower projects.

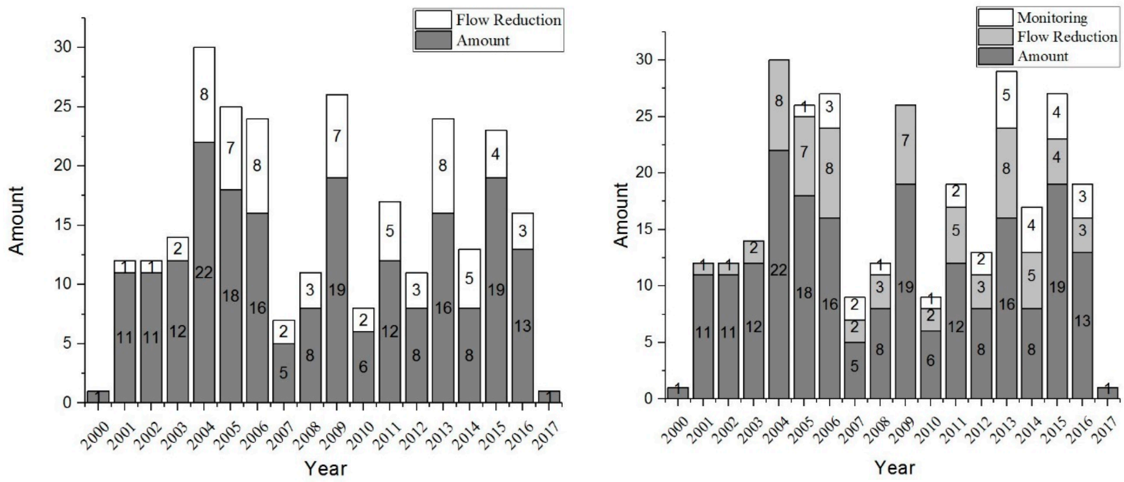
Category	Type	Number
Project type	Diversion	23
	Dam	100
	Mixed	16
	Unknown	67
Regulation	Multi-year	46
	Semi-annual	7
	Annual	26
	Seasonal	13
	Weekly	5
	Daily	67
	No	42

3.2.2. Construct Types and Flow Reduction Events

The impacts of different types of water storage and hydropower projects on downstream rivers were also analysed.

In our database, among the 206 water storage and hydropower projects, a total of 69 led to downstream flow reduction among which 54 were hydropower projects and 15 were water storage projects (Figure 3a). Regarding the project types, there were 35 dam projects, 23 diversion projects and 11 mixed projects that caused flow reduction.

Also, about 137 water storage and hydropower projects did not cause flow reduction events, including 40 hydropower projects and 97 water storage projects (Table 2).



(**a**) (**b**)

Figure 3. (**a**) Temporal distribution of projects caused flow reduction in China for 2000 to 2017; (**b**) temporal distribution of projects caused flow reduction with ecological flow monitoring.

Table 2. The number of water storage and hydropower projects that caused flow reductions in rivers.

Engineering Type	Flow Reduction	Quantity	Project Type			
			Diversion	Dam	Mixed	Unknown
Hydropower project	Yes	54	11	33	10	
	No	40	0	36	4	
Water storage project	Yes	15	12	2	1	
	No	97	0	29	1	67
Total		206	23	100	16	67

3.3. Biological Protection

Analyzing important and protected animals in river ecosystems is the main objective behind the decision-making related to ecological flow management. The scope of protecting red-listed species in China covers the protection of important fish at national and provincial levels, and these fish are included in the "Red Book of Endangered Animals in China".

According to statistics, only 7 (5 hydropower projects and 2 water storage projects) of the 69 events that caused flow reduction did not affect red-listed species. The other 62 events impacted red-listed species and their corresponding spawning grounds.

3.4. Ecological Management

Due to the diversity of ecosystem services, multiple targets can be used to evaluate downstream health conditions, such as shipping flow, environmental flow and baseload electricity generation, etc. In China, there were no ecological flow requirements before 2000, and most of the water storage and hydropower projects did not consider downstream ecosystems. There was no guide to calculate the amount of ecological flow needed to sustain different functions until 2005, but this situation changed in 2006 when the base flow was considered the most important targets, and a quality standard for base flow was established.

3.4.1. Ecological Flow Implementation

Of the 69 water storage and hydropower projects that caused flow reduction, 67 were identified to release the ecological base flow, and 2 projects did not consider released ecological base flow. Of the 67 water storage and hydropower projects that released ecological flow, 52 were hydropower projects, and 15 were water storage projects.

Regarding temporal distribution, 8 water storage and hydropower projects that caused flow reduction in downstream reaches were constructed before 2006, while 61 projects were constructed after 2006.

Of the 8 projects that had been implemented before 2006, 6 projects maintained specific base flows due to the need to generate energy, and 2 projects did not consider alleviating the impacts of flow reduction. This phenomenon changed after 2006, and all projects were obliged to release ecological base flow (Table 3).

Table 3. Water storage and hydropower projects of ecological flow implementation.

Engineering Type	Time	Quantity	Ecological Flow Implemented
Hydropower projects	Before 2006	7	5
	After 2006	47	47
Water storage projects	Before 2006	1	1
	After 2006	14	14
Total		69	67

3.4.2. Ecological Flow Monitoring

Considering that China explicitly did not introduce ecological flow schemes until 2006, the monitoring of the ecological flow by water storage and hydropower projects therefore began after the promulgation of the policy.

Based on data analysis results, 61 water storage and hydropower projects met the ecological flow conditions after 2006, including 47 hydropower projects and 14 water storage projects.

Among the 47 hydropower projects, 15 had online ecological flow monitoring systems, and 32 had not yet established flow monitoring systems. One of the 14 water storage projects did not have an ecological flow monitoring system; the rest had monitoring facilities (Figure 3b).

In summary, a total of 61 projects caused flow reduction after 2006, of which 28 had monitoring systems and 33 did not. The detailed data are shown in Table 4.

Table 4. Water storage and hydropower projects with ecological flow monitoring.

Engineering Type	Quantity	With Monitoring	Without Monitoring
Hydropower	47	15	32
Water storage	14	13	1
Total	61	28	33

3.4.3. Ecological Flow Method

Among the 61 water storage and hydropower projects discussed above, the hydrological method was the most widely used method to calculate ecological flow, and this method was used by 80% of the projects. The second most common method used was the physical habitat method, which was used to calculate the ecological water demands of endangered animals in downstream reaches during their spawning periods, and this method used 10 times. The third most common method used was the hydraulic method, which was used 8 times and was just used as a comparison programme. The comprehensive method was not used in the EIAs.

There were still nine projects which had discharged base flow that considered shipping, power generation and other integrated traffic demands (Table 5).

Table 5. Calculation methods and statistics for ecological flow.

Calculation Methods	Quantity
Hydrological method	**51**
Minimum average monthly flow over 10 years	5
Minimum daily average flow method	2
Flow via the curve method	2
Tennant method	33
5% of the average annual flow	9
Hydraulic method	**8**
Wetted perimeter method	3
R2Cross method	5
Physical habitat method	**10**
PHM method	6
Ecological hydrodynamic method	4
Other	**9**
Baseload power generation flow	5
Shipping base flow	2
Ecological water demand	2

4. Discussion

4.1. Characteristics of Water Storage and Hydropower Projects

The spatial distribution was discussed by watershed regions. Of all the water storage and hydropower projects (206), approximately 70% were distributed in the Yangtze River basin, the Pearl River basin and the South-west river basins in China. These areas have abundant water resources, and the spatial distribution of water storage and hydropower projects is essentially consistent with the distribution of hydropower resources in China.

The results show that the projects characteristics have different effects on the downstream river courses. More than 30% of dam projects, compared 100% of the diversion projects, and 70% of the hybrid projects caused flow reductions in downstream rivers.

Therefore, diversion projects have a greater impacts than other project types on river ecosystems. In addition, hybrid projects have the same characteristics as the aforementioned water storage and hydropower projects.

Approximately 1/3 of the projects in our database caused flow reduction, but the impacts of water storage projects and hydropower projects on downstream rivers differ from each other.

Hydropower projects can cause severe flow reduction in downstream rivers, and 60% of hydropower projects have caused flow reduction in China. Of the hydropower projects, more than half of the embankment projects, most of the hybrid projects and all of the diversion projects have caused flow reduction in downstream rivers, and these projects have a considerable impact on downstream river ecosystems.

According to the analysis, less than 15% of the rivers downstream of water storage projects experienced flow reduction. The flow reduction phenomenon associated with water storage projects may be caused by water shortages resulting from excessive water diversion.

The capacity to regulate the water flow of small-sized projects is generally below the monthly regulation capacity, mostly in daily or non-regulation projects. No regulation projects is also named a diversion project which will cause flow reduction in downstream river sections. According to the analysis, approximately 90% of the projects constructed after 2000 are small-sized projects.

The current research is mainly directed at large-scale water storage and hydropower projects with relatively high regulation performance in China. However, small-sized projects, especially a large number of small-sized projects, also have great impacts on downstream river ecosystems, and with the acceleration of the construction of small water storage and hydropower projects, attention should be paid to their impacts on aquatic ecosystems.

4.2. Ecological Flow Management Features

4.2.1. Status of Ecological Flow Implementation

As the quantitative standard for the ecological base flow was first established in 2006, we analysed the implementation of ecological flow regulations at water storage and hydropower projects before and after 2006.

A total of 8 projects in our database caused flow reductions before 2006, and 6 of them implemented a certain base flow due to the demands of baseload power generation or other factors. In addition, after the change in this phenomenon in 2006, 61 water storage and hydropower projects formulated measures to protect the stability of downstream river ecosystems by guaranteeing discharges that ensured ecological base flow.

Actually, there was no guide for quantifying the amount of ecological flow before 2006, and the number of projects that caused flow reductions is larger than 8, but the EIA reports may not record this phenomenon. From the statistic results, there were no more than 75% of projects that were built before 2006 implemented ecological flow, and all of the projects that were built after 2006 implemented ecological flow. Thus, the management of ecological flow in China has played a positive role in maintaining the stability of downstream river ecosystems.

4.2.2. Calculation Method and Its Adaptability

Of the methods used by the water storage and hydropower projects mentioned above to calculate ecological flow, the most popular method was the hydrological method, whereas only a few projects used the physical habitat method to analyse ecological flow.

In our database, we found that the Tennant method was the most widely employed among the hydrological methods used to calculate ecological flow. We think there are mainly two reasons for this:

(1) In China, there were no ecological flow requirements before 2000, and most of the water storage and hydropower projects did not consider the downstream ecosystems. There was no guide for quantifying the amount of ecological flow until 2005, but in 2006 the 'Technical Guide for Environmental Impact Assessment of River Ecological Flow, Cold Water, and Fish Passage Facilities for Water Conservation Construction Projects (Trial) EIA Letter [2006] No.4' was issued by the State Environmental Protection Administration. This document was the first to define the concepts and methods used to measure ecological flow in the EIA, and it identified an annual average flow of 10% as the minimum flow. However, a standardised guide line giving advice on methods and an accurate minimum flow has still not been implemented. Based on this background, the choice of ecological flow method in EIA seems arbitrary.

(2) The Tennant method was first proposed by Tennant et al. in 1967, in which 10% of the average annual flow was the minimum. This method is simple and easy to implement, and has a low requirement of data, which led it to become one of the most widely used methods in the world and also be one of the recommended methods in the "Technical guide" by China in 2006.

However, this method only uses simple indicators to identify the ecological base flow, and the scope of the application of this method in China is not yet clear. There are many problems associated with blindly using this method. Moreover, some water storage and hydropower projects use an average flow rate of only 5% to represent the ecological flow.

In addition to the species currently protected in areas downstream of water storage and hydropower projects, there are other important and protected organisms in most downstream areas. Therefore, if the result calculated by the hydrological method is used as the only ecological base flow, there will be a lack of justification to protect biological habits.

4.2.3. Monitoring

Statistically, of the 61 water storage and hydropower projects, only approximately 45% of the projects have established a monitoring system for ecological flow. The remaining projects have not established a monitoring system, which brings a substantial amount of uncertainty to the supervision of ecological flow. The managers are unable to determine the appropriate amount of water to discharge to meet the ecological flow requirements.

Monitoring schemes could help evaluate whether or not the regulations have had an effect, calling for establishment of an ecological flow monitoring system.

4.3. Management Recommendations

One point of ecological flow management is to formulate appropriate flow to maintain the stability of the downstream river ecosystem, and one of the difficulties is how to quantify the flow standard [28]. Currently, EIAs suggest ecological flow regulations for water storage and hydropower projects, and this process has improved and optimized the regulations of water storage and hydropower projects. However, as discussed above, there are still some problems which remain to be addressed. Therefore, this paper analyses the ecological characteristics of water storage and hydropower projects in China, especially those that cause flow reduction in rivers, and proposes that ecological flow management should follow a model based on the regional-engineering and computing method.

4.3.1. Spatiotemporal Management Model

China's water storage and hydropower projects cover a large geographic area, and the ecological characteristics of regions differ greatly. Due to the spatial and temporal variabilities of ecological characteristics, ecological management should consider establishing a spatiotemporal management model. The management practices in different regions will vary according to the ecological characteristics of each region.

The concept of hydro-ecological zones originated in the United States and was first proposed by Omernik in 1987 [29]. The foundation of these zones is the classification of water bodies at a specific scale [30]. The advantages of ecological water zoning in water environment management, the biological evaluation of rivers, and wetland management are obvious and can facilitate unified management of water bodies in an area and identify appropriate calculation methods [31]. Therefore, ecological flow management should establish a set of ecological water zones suitable for China and formulate appropriate management guidelines and policies for different regions at different times.

4.3.2. Management Rules for Engineering Characteristics

When projects are planned, there should be a comprehensive survey of downstream areas, including sensitive targets. The survey should include assessments of effects on red-listed species and other factors such as wetlands, avifauna, pollution distribution and reserves. In addition, the need to establish protected habitats should be analysed.

Therefore, the analysis of ecological flow needs to use water regulation engineering as an object, analyse whether there are important targets for aquatic protection under the dam, and choose suitable methods to calculate the ecological flow.

4.3.3. Ecological Flow Calculation

The calculation method is an effective quantitative method to calculate ecological flow. The hydrological method is mostly used during EIAs, and the ecological characteristics of the lower reaches of a river are not considered. Consequently, this process can result in many ecological problems.

According to the advantages and disadvantages of various methods, a suitable calculation method should be selected to calculate the ecological flow, and the results should be analysed.

(1) Data from the study area are analysed to determine whether the data meet the requirements of the utilized calculation methods.
(2) In downstream areas harbouring red-listed or protected species, the reproductive characteristics of the protected organisms should be fully considered, and the habitat method or holistic method should be used to analyse the minimum discharge required for ecological base flow to ensure that the conditions necessary for spawning of aquatic organisms are met.
(3) In general, downstream areas without red-listed or protected species, the hydrology or hydraulics methods could be used to calculate the ecological base flow. In a case with abundant data, the ecological hydrodynamics method or the whole analysis method should be used to analyse the rationality of the calculation results.

4.3.4. Management Monitoring

After completing the above management steps, it is necessary to evaluate whether the ecological management policy is properly implemented. Currently, China's ecological flow monitoring system has not yet been fully established, and policymakers are still unable to supervise the degree of implementation and the effectiveness of ecological flow management. In the future, it is suggested that authorities should enforce policies related to the construction and operation units of water storage and hydropower projects and require that an ecological flow monitoring system be part of the evaluation used in the EIA.

4.3.5. Management Optimization

Finally, it is still necessary to adopt adaptive management methods to adjust the ecological base flow process in a timely fashion according to the ecosystem protection status, to analyse the effect of the hydrological process on the ecosystem, and establish the relationship between the ecological flow and the ecosystem quality. By adjusting and refining the library of appropriate calculation methods, a collection of appropriate calculation methods is established to dynamically update ecological base flow values.

5. Conclusions

The water storage and hydropower projects in China are mainly concentrated in the south-west, and new water storage and hydropower projects are mainly medium and small in size. Approximately 1/3 of these projects cause flow reductions in downstream rivers, especially diversion hydropower projects, which have a large influence on ecosystems. The practice of ecological flow management plays a positive role in the ecological protection of downstream river reaches. After implementing ecological flow management, the flow reduction phenomenon downstream of water storage and hydropower projects has improved, and flow reduction events at the lower reaches of the rivers were basically eliminated after 2006. At the same time, a variety of ecological flow calculation methods are used synthetically, which greatly improves the application of ecological flow measures in China.

Although ecological flow management has played a positive role in the protection of river ecosystems, a series of problems remain, such as the blind calculation of ecological flow, the unreasonable calculation of ecological flow rates, and the ineffective monitoring of ecosystems. Therefore, in the future, the management of ecological flow can be determined according to the proposed regional engineering method to optimise the ecological flow calculation method, the base ecological flow standard, and the ecological adaptability of the regulatory system; these changes will provide basic research support for the development of ecological flow management policies.

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