Research on the water resources regulation ability model of
dams in the Huai He River Basin considering ecological and
management factors

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Abstract. Research that assesses the scheduling ability of dams garners a great deal of attention
due to the global water resource crisis. These studies can provide useful and practical suggestions
for scheduling the water resources of dams to solve problems, such as addressing ecological water
needs and so on. Recent studies have primarily evaluated the schedule ability of dams according
to their quantifiable attributes, such as water quantity, flow velocity, etc. However, the ecological
and management status can directly determine the possibility and efficiency of a dam’s water
resource scheduling. This paper presents an evaluation model to assess the scheduling capacity of
dams that takes into consideration ecological and management factors. In the experiment stage,
this paper takes the Sha Ying river of the Huai He River Basin as an example to evaluate the
scheduling ability of its dams. The results indicate that the proposed evaluation model can provide
more precise and practical suggestions.

1. Introduction
Recent studies evaluating the scheduling abilities of dams have increased amidst wide concerns about the
global water resource crisis \cite{8}. However, past research has primarily focused on water schedule on flood
control, drainage, water supply, pollution prevention, control, and so on \cite{7}. With the development of
social economy and the increased efficiency of water resources, water ecology has been attracting a great
deal of attention \cite{11}. Past studies assessing the water schedule ability of dams were more concerned
about water quantity and water quality but ignored the importance of the management status of dams \cite{2}.
To the best of our knowledge, related researchers avoided taking both management and ecological factors
into consideration during their modeling for assessing water schedule ability \cite{5}. However, the ecological
and management factors can have a serious effect on the water schedule ability of dams \cite{3}. Thus, some
researchers adopted these qualified factors to obtain an imprecise assessment of dam scheduling ability
\cite{4}. Nonetheless, these indexes can be quantified and considered in order to make precise evaluations of
dam scheduling abilities with scientific approaches \cite{6}. This paper investigates fifty experienced experts
who have been working on managing related dams for many years and obtains their rates on the
management status of the dams. As for the ecological factors, this paper utilizes water quantity and the
density of NH\textsubscript{3}-N and COD elements, which are critical influences on the ecological status of water
around dams, to represent the water ecology variable.

2. Materials and Methods

2.1. Dams information
In this paper, the dams selected are primarily located in the Huai He River, which is one of the most
important and largest rivers in China.
Figure 1. Dam layout in the Yin Shang control section.

Figure 1 illustrates the layout of the Yin Shang control section. From this figure, it can be seen that many control sections reside along the Huai He River division, and there are many dams and reservoirs along with the Yin Shang control section.

2.2. Evaluation model

For evaluating the specific schedule ability of dams, this paper constructs an assessment model that includes seven influential factors: water quantity that dams are able to use (V1), the water transmitting time of the schedule (V2), status of getting water along the river of a dam (V3), environmental remains of different contaminants (V4), dam management status (V5), construction status of dams (V6), and emergency handling capability of dams (V7). These factors can be classified into three aspects, which are included into the model as figure 2.

![Figure 2. Dam Layout of the Yin Shang Control Section.](image-url)
From figure 2, the factors affecting the scheduling ability evaluation of a dam can be divided into three categories. This model depicts how the factors are composed and how they influence the scheduling ability assessment of dams.

2.3. Evaluation Indexes
Based on past research, the evaluation indexes for assessing the schedule ability of dams mainly considered water quantity and water ecological factors. However, management factors are also critical when assessing dams’ schedule abilities. This paper optimizes the factors considered in the past and presents new indexes according to practical conditions. The meanings of the indexes are shown in the following.

2.3.1. Water quantity that dams are able to use. The water quantity that a dam is able to schedule represents the amount of water that a dam is free to use. This index indicates the scheduling possibility and ability rather than the total water amount of a dam. The specific calculation process can be depicted by formula 1.

\[ W = \eta \times (w_1 - w_2) \]  

In Equation 1, W is the water quantity that a dam is capable of using, \( w_1 \) is the total amount of water in a dam, and \( w_2 \) is the water quantity that a dam is unable to utilize. The ratio \( \eta \) is a water scheduling attribute of a dam; when \( \eta \) equals 1, the total water can be used for scheduling, and when \( \eta \) equals 0, no water can be scheduled. In reality, the water of a dam cannot be used up due to the existence of restrictions imposed by the dam and other urgent emergency concerns, such as shipping. Thus, the ratio \( \eta \) can make the water quantity factor more reasonable and practical.

2.3.2. Water transmitting time of the schedule. When a place requires water for ecological problems, a dam requires time to transmit water to the place. In the Huai He River, this dam index is mainly decided by the dam’s distance from the control section of the river. This can be explained by figure 1. A hybrid model combining hydrodynamic effects has been developed to describe the water flow and its time [9] [10]. According to the model, this factor can be calculated. Thus, taking this factor into consideration can express the urgent aspect of the schedule ability of dams.

2.3.3. Status of getting water along the river of a dam. The status of getting water along the river of a dam describes the status of the scheduling water being stopped and used during the process of transmitting it to the destination. This parameter can influence the amount of water that reaches an ecological control section, which affects the water scheduling of a dam.

This paper utilizes fifty experienced experts who previously worked in this area for a long time. The experts rate this factor for each dam, and two rating criterions are established for them. The rating standards are the water number used and the number of dams that exists during the process when the water was transmitted from the dams to the ecological control section, and the results of the control section are listed in Table 1.

From the table, the specific evaluation score for an expert to a dam on V3 can be obtained. Thus, removing the largest and smallest score of a particular dam, obtain the value of V3 can be obtained as equation 2.

\[ S_j = \frac{\sum_{i=1}^{m} RD_{ij}}{n-2} \quad (i \neq ima, imi) \]  

In equation 2, \( S_j \) is the V3 value of Dam \( j \); \( RD_{ij} \) means Rater i rates the ability of Dam j, which ranges from 0-5; \( m \) represents the number of dams along the control section; and \( n \) is the effective expert’s rating. Furthermore, \( ima \) and \( imi \) are the maximum and minimum raters for rating the ability of dam \( j \), respectively. In this paper, five dams above the Yingshang control section were selected as research objects. The five dams include Zhou Kou, Huai Dian, Gen Lou, Fu Yang, and Yin Shang. The five dams are marked as Dam 1, Dam 2, …, Dam 5, respectively.
Table 1. Score table for V3.

| Raters | Dam 1 | Dam 2 | ... | Dam m |
|--------|-------|-------|-----|-------|
| Rater 1 | RD_{11} | RD_{12} | ... | RD_{1m} |
| Rater 2 | RD_{21} | RD_{22} | ... | RD_{2m} |
| ... | ... | ... | ... | ... |
| Rater n | RD_{n1} | RD_{n2} | ... | RD_{nm} |

2.3.4. Environmental remains of different water quality parameters. The environmental remains of different contaminants are taken into consideration for evaluating the dams’ purifying water ability. The better this factor, the higher the purifying ability of the water in the dam is, which also means there is a higher water quality. This factor can be calculated as follows.

\[ R = 100 \times (C_0 - C_1) \]  

From equation 3, this factor is represented by R. \( C_0 \) is the standard water quality in water function zones, which can be defined according to [1]. The number 100 is the unit exchanging ratio, and \( C_1 \) is the water quality of the dams. In this case, it can be concluded that the higher the R value, the more purified the water is in the relevant dams.

As for water quality, this paper calculates two water quality parameters, \( \text{NH}_3-N \) and COD, as representatives for assessing the dams’ water quality. In this case, equation 3 can be modified into Equation 4.

\[ R = 100 \times \frac{\alpha \times (C_{\text{NH}_3-N} - C_{\text{NH}_3-N}) + \beta \times (C_{\text{COD}} - C_{\text{COD}})}{\alpha + \beta} \]  

From equation 4, \( \alpha \) represents the weight of \( \text{NH}_3-N \), while \( \beta \) is the weight of COD. Thus, by Equation 4, the value of the environmental remains of the water quality parameters can be obtained.

2.3.5. Dam management status. Dam management status is an index explaining how the dams are utilized, and whether it is easy to schedule the water. This paper adopts the same approach for obtaining its values as was done for V3. Thus, this evaluating index can be defined.

2.3.6. Construction status of dams. The construction status of a dam is the current status of a dam that can affect its scheduling ability. This paper rates a dam’s construction status as a 0-5 score according to its build time, maintenance time, dam level, and research results. For a specific dam, a rating table can generated, such as Table 2.

Table 2 gives the four indexes for calculating the construction status of a dam. The first three indexes, the dam build time, dam maintenance time, and dam level can be defined by looking up relevant literatures. As for the fourth index, the research results score can be generated by assessing whether the dam has a flow monitoring facility and a security facility for ecological flow. Using all of the scores in Table 2, this paper calculates the construction status of dams according to Equation 5.

\[ C = \frac{\varepsilon \times RB + \phi \times RM + \varphi \times RL + \gamma \times RR}{\varepsilon + \phi + \varphi + \gamma} \]

Table 2. Rating table for V6.

| Raters | Build time | Maintenance time | Dam level | Research results |
|--------|------------|------------------|-----------|------------------|
| Rater 1 | RB_{11}   | RM_{12}          | RL_{13}   | RR_{14}          |
| Rater 2 | RB_{21}   | RM_{22}          | RL_{23}   | RR_{24}          |
| ...    | ...       | ...              | ...       | ...              |
| Rater n | RB_{n1}   | RM_{n2}          | RL_{N3}   | RR_{n4}          |
C represents the final value for this factor. The coefficients $\varepsilon$, $\phi$, $\varphi$, and $\gamma$ of the indexes show the weights of the four indexes, respectively. Moreover, the value of the indexes in Equation 5 can be calculated according to the method for determining V3.

2.3.7. Emergency handling capability of dams. The emergency handling capability of a dam is an index evaluating the ability of a dam to cope with emergencies, which is a factor that can affect the water scheduling ability of a dam. This paper calculates this value in the same method by which V3 is calculated. Thus, the value of this factor can be defined in a scientific approach.

3. Experiment
This paper employs the Yin Shang control section of the Huaihe River as an example for performing the experiment. In this experiment, this paper adopts the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to implement the model, and all the data comes from the Key State Science and Technology Project (2014ZX07204-006-05). TOPSIS is a commonly used approach for evaluating regulation ability [12]. The results are shown in table 3.

| Dams       | V1   | V2   | V3   | V4   | V5   | V6   | V7   |
|------------|------|------|------|------|------|------|------|
| Zhou Kou   | 445  | 259.3| 3    | 1.00 | 2    | 3    | 3    |
| Huai Dian  | 82   | 133.1| 2    | 0.74 | 2    | 3    | 2    |
| Geng Lou   | 3970.61 | 143.7| 2    | 0.24 | 2    | 2    | 2    |
| Fu Yang    | 2875 | 78.4 | 1    | 0.41 | 3    | 2    | 2    |
| Ying Shang | 5431.46 | 0    | 1    | 0.07 | 5    | 4    | 5    |

From the results, it can be determined that the Yin Shang dam is the best dam of the five dams because it has the best scores for the V1, V2, V3, V5, V6, and V7 indexes. The new factors model for evaluating dams’ regulation abilities combined with the adopted assessing approach can give a specifically quantifiable number of the ability. The model is useful and practical for managers to regulate dams.

4. Discussion
This paper presents a new model for evaluating the water scheduling ability of dams, which can provide practical suggestions to related managers to make the best choice to maintain ecological water needs. In a follow-up study, further research can be conducted to determine the best algorithm to simulate the scheduling process based on the evaluation results. Additionally, based on this new model, researches on finding the best way to implement this model can be performed in detail.

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