Application of evaluation indicators for assessing the influence of reservoirs on downstream water temperature

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***Abstract*—To research the water temperature cumulative effect of the power station cascade development, taking the upper reaches of the Yellow River from Ningmute to Maerdang as an example. In the paper, the water temperature impact evaluating indicator was used, combined with three-dimensional model to simulate the distribution of the reservoir area water temperature in its six work conditions. The water temperature affect characteristics of the Maerdang reservoir was reflected intuitively and clearly. When the Maerdang reservoir run separately, the effects of water temperature was small than jointly run. The minimize of the water temperature effect is the separately run wet years condition, while the maximum is jointly run dry year conditions. The baseline deviation from the indicators can intuitively reflect the Maerdang reservoir from month to month, the heating and cooling season and year-round water temperature deviate characteristics. The phase deviation indicators precisely water temperature hysteretic effect. The extremal change indicator vividly describes the effect of water temperature planarizing effect. The application of evaluation indicator can provide a scientific basis for the rational development and utilization of the period for river, reservoir optimal scheduling.**

***Index Terms*—the upper reaches of the Yellow River, water temperature, cumulative effect, evaluation indicators.**

I. INTRODUCTION

The cascade development can make use of the water resources of the river to maximize, however, it will also have a series of negative impact on ecological environment. The water temperature as an important factor affecting the ecological environment, the survival and reproduction of aquatic life, downstream irrigation of crops, the river's ecological environment is closely related to it [1]. Therefore, water temperature environmental impact has become one of the important problems to study the environmental impact of hydropower project water. The fluctuations of river water temperature related to factors such as weather conditions, human activities and hydrological processes [2]. Damming of human activities on the river water temperature has been widely reported. The greater the degree of regulation of reservoir operation, the more significant discharged water temperature affect , especially the reduction of daily maximum water temperature and spring water temperature warming delay would interfere with fish spawning process [3].

Currently, the reservoir of the river water temperature includes two aspects: First, the effect of dam on release water temperature; Second, the effect of reservoir water temperature. The former is to consider the water temperature as an single water quality variables, analysis of reservoir regulation in response to changes in water temperature relationship; the latter is based on the water temperature threshold of survival and reproduction of river aquatic organisms, transformation of river water quality and irrigation of crops analyse the reservoir change river water temperature caused the effect of the environmental impact, the latter is basis of former [4-5]. Reservoir water temperature impact studies usually take the fluctuations of the different time scales feature extreme water temperature and amplitude difference to reflecting the diversity of before and after building a reservoir. The evaluation limited to descriptive analysis, the lack of a unified quantitative evaluation difficult to identify adjusted and compare different characteristics of the reservoir and the cascade reservoirs water temperature characteristics [6]. In response to this situation, Song etc. try to build a common set of quantitative evaluation to reflect reservoir water temperature affect the characteristics of the law. In this paper, one of the key river basin hydropower development in the upper reaches of the Yellow River as an example , the use of the water temperature impact assessment index system , reveals the cascade development of the law of the cumulative effect of the river water temperature to ensure that the cascade built environment of the upper reaches of the Yellow River are effectively protected, carried out on the upper reaches of the cascade hydropower planning has important guiding significance .

II. RESEARCH METHODS

A. Methods principles

Taking the upper reaches of the Yellow River from Ningmute to Maerdang as an example, there are two planning power stations in the reach. From upstream to downstream, respectively, Ningmute and Maerdang reservoir, the two reservoir are shown in Table 1. Select Maerdang reservoir two operating modes: the separate operating mode and the combined operating mode, consider the flat, dry, and abundance of three typical hydrological year, corresponding to condition 1 to condition 6.

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TABLE I. Characteristic values of the reservoirs located in the research area

Hydropower Station Name	**reservoir capacity /(hundred million m^3/s)**	**Years of runoff /(hundred million m^3/s)**	**Reservoir length/km**	**The maximum dam height/m**
Ningmute	44.57	149.48	157.3	139
Maerdang	21.85	149.48	117.6	119

The three-dimensional mathematical model which has parameter calibration was adopted to simulating the water temperature distribution in the reservoir of the six work conditions. Which can provide a scientific basis for the rational development and utilization of the period for river, reservoir optimal scheduling. The three-dimensional mathematical model of the process of inflow water temperature which required for the simulation of the reservoir area water temperature were shown in Figure 1.

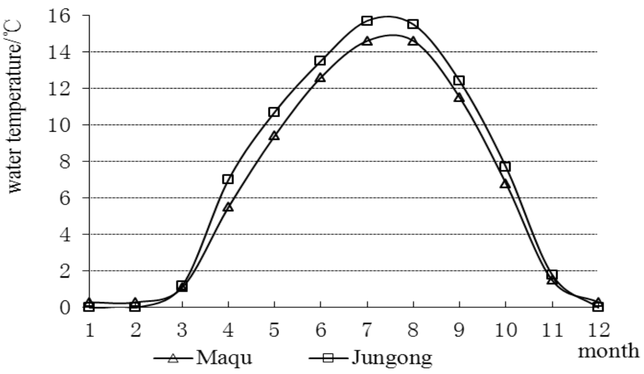

Fig. 1. Observation data of water temperature in different months

B. Water temperature impact assessment indicators

The three types of evaluation evaluation indicator were established from fluctuation of the analysis of the river water temperature in the reservoir disturbance reservoirs on the river water temperature [7].

1)The baseline deviation:

The baseline deviation defined as the relative value of the deviation from the reference water temperature of the river water temperature and natural rivers database, its expression formula is:

$$I_{BD}=\sum_{i=1}^{12}(T_{i,c}-T_{i,n})^2/\sum_{i=1}^{12}(T_{i,n}-\overline{T})^2 \qquad (1)$$

Where I_{BD} is the year deviate from the indicators ; $T_{i,c}$ is after the construction of reservoirs the i month of the river water temperature,℃; $T_{i,n}$ is the i month natural rivers baseline water temperature,℃; T is the annual average natural river the benchmark water temperature of, ℃ ; i is month (i =1,2,3…12)。

2) The phase deviation:

The phase deviation defined as the relative value of the river water temperature after building a database with the natural river the benchmark water temperature of the phase difference, which was expressed as:

$$I_{PS}=(D_c-D_n)/P_{\max} \qquad (2)$$

$$D_c=\arctan(T_{x,c}/T_{y,c}),\quad T_{x,c}=\sum_{i=1}^{12}T_{i,c}\sin\theta_{i,c},\quad T_{y,c}=\sum_{i=1}^{12}T_{i,c}\cos\theta_{i,c} \qquad (3)$$

$$D_n=\arctan(T_{x,n}/T_{y,n}),\quad T_{x,n}=\sum_{i=1}^{12}T_{i,n}\sin\theta_{i,n},\quad T_{y,n}=\sum_{i=1}^{12}T_{i,n}\cos\theta_{i,n} \qquad (4)$$

Where I_{PS} is the phase deviation ; D_c and D_n were concentrated period of river water temperature after building reservoir and natural baseline water temperature (azimuth translated into the number of days), d; P_{max} is the maximum phase shift amount, d; $T_{x,c}$, $T_{y,c}$, $T_{x,n}$ and $T_{x,n}$ are water temperature of each month in the horizontal and vertical direction component of synthetic after building reservoir and natural baseline, ℃; $\theta_{i,c}$ and $\theta_{i,n}$ are vector angle after building reservoir and natural baseline, the first month after the water temperature .

3) The extremal change:

The extremal change defined as the river water temperature ranged from building a database of the ratio of the amplitude of the of natural rivers benchmark water temperature , which was expressed as :

$$I_{EC}=(T_{\max,c}-T_{\min,c})/(T_{\max,n}-T_{\min,n}) \qquad (5)$$

Where I_{EC} is the extremal change; $T_{max,c}$ and $T_{min,c}$ is the water temperature monthly maxima and minimum value of the river after building reservoir , ℃; $T_{max,n}$ and $T_{min,n}$ are the water temperature monthly maxima and minimum value of natural baseline , ℃;

Because the proposed indicators are dimensionless number, the evaluation of the impact effect is to consider the nature of the classification affect different waters. Water temperature requirements vary widely by setting the water temperature requirements and the indicators of the impact object defined water temperature affect the nature indicators and to determine the grading standards.

III. RESULTS AND ANALYSIS

In this paper, the influence of the Maerdang reservoir on water temperature is assessed by multi-index evaluation method, of which three indexes, baseline deviation , phase deviation and extreme value deviation, are taken into consideration.

A. The baseline deviation

Based on the assumption that temperatures of the river water and of the Maerdang reservoir discharge water are similar to each other after the Maerdang reservoir putting into service, six operating modes are analyzed in the paper. Taking monthly river water temperature data measured before the construction of the Maerdang reservior as the baseline, monthly river water temperature deviation indexes after the completion of Maerdang reservoir are calculated, and then conclusions are made according to the analysis of the calculated results.

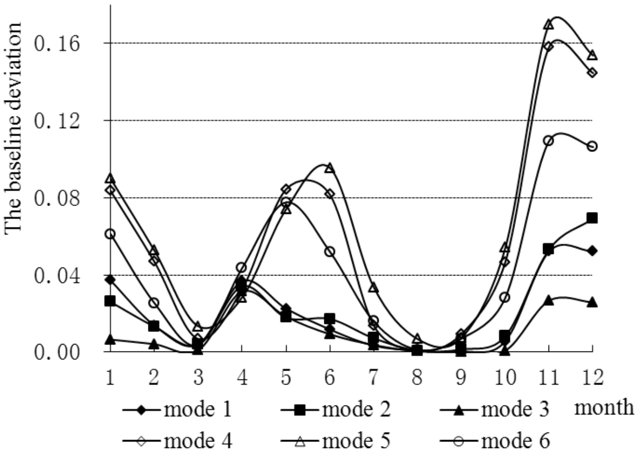

Fig. 2. Monthly baseline deviation of 6 different oprationg modes of the Maerdang reservoir

Taking monthly river water temperature data measured before the construction of the Maerdang reservoir as the baseline, monthly water temperature deviations of 6 different operating modes of the Maerdang reservoir are shows in Figure 2.As it can be seen from the Fig.2: changes have taken place after the Maerdang reservoir being put into use, and water temperature deviations in March, June, July, August and September are much smaller than the ones in the cold period from October to the following February; Max. deviations of different operating modes all occur in November; in the warm period, obvious monthly water temperature deviations take place except from July to September; under the three separate operating modes, Max. deviations all happen in April while under combined operating modes, Max. deviations in warm period happen in May as for mode No.4 and mode No.6, and in June as for mode No.5; under all the six picked operating modes, whatever in warm period or in cold period , Max. deviations both happen once a year, but they are different from the counterparts, relatively smaller during the warm period.

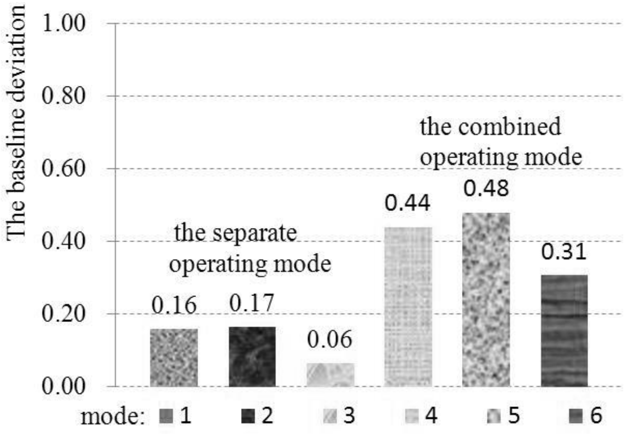

Fig. 3. Monthly baseline deviation of the Maerdang reservoir during the cold period

In the Maerdang reservoir Area, the cold period lasts from November to the following March, while the warm period lasting from April to October. Relatively water deviation indexes can be calculated separately according to different temperature periods, using $I_{BD,cold}$ for the cold period while $I_{BD,warm}$ for the warm period, and then the annual deviation index can be known by adding $I_{BD,cold}$ and $I_{BD,warm}$ up. Figure 3 and 4 shows relatively water temperature deviation indexes of the Maerdang reservoir in different temperature periods.

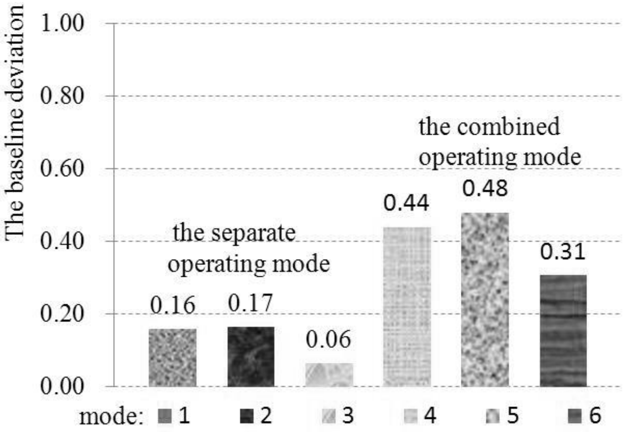

Fig. 4. Monthly baseline deviation of the Maerdang reservoir during the warm period

It can be seen from Fig.3 and 4 that: during the cold period, water temperature deviations under the condition of separate operating mode are about one-third as they are under the condition of combined operating mode in all the three picked water quantity periods: the flood period, the average water period and the dry period, which means that combined operating mode between the Ningmute reservoir and the Maerdang reservoir can enhance water temperature effects, and the similar changing regulation can be applied to the water temperature deviations during the warm period, only that the water temperature deviations under the condition of separate operating mode are about one-fourth as they are under the condition of combined operating mode in all the three picked water quantity periods; comparing the water temperature deviations under the 6 operating modes, it can be concluded that the construction of the Maerdang reservoir results in greater influence on water temperature in cold period than it does in warm period; whatever the operating modes are, the influence on water temperature caused by the construction of Maerdang reservoir is inversely proportional to different water periods, which means the greatest influence occurs in the dry period.

B. The phase deviation

Taking the river water temperature phases measured before the construction of Maerdang reservoir as the baseline data, figure 5 gives the river water temperature phase deviations under different conditions, from which it can be seen that the phase deviation values are relatively small of both the separate and the combined operating modes, which means that the lag effect caused by the construction of Maerdang reservoir is not obvious, however, with the phase deviation of about 20 days the combined operating mode still has a greater influence on river water temperature than the separate operating mode does, in which case the phase deviation value is about 10 days. As for the relationship between water temperature phase deviations and water periods, they are inversely proportional to each other. Thus, taking both the operating modes and the water periods into consideration, it can be seen from Fig.5 that the minimum phase deviation occurs under the assumption of dry period together with the separate operating mode while the maximum phase deviation occurring under the assumption of flood period together with the combined operating mode.

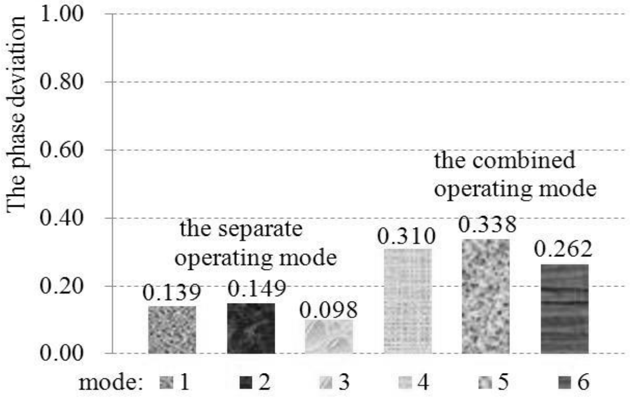

Fig. 5. The phase deviation caused by the construction of the Maerdang reservoir

C. The extremal change

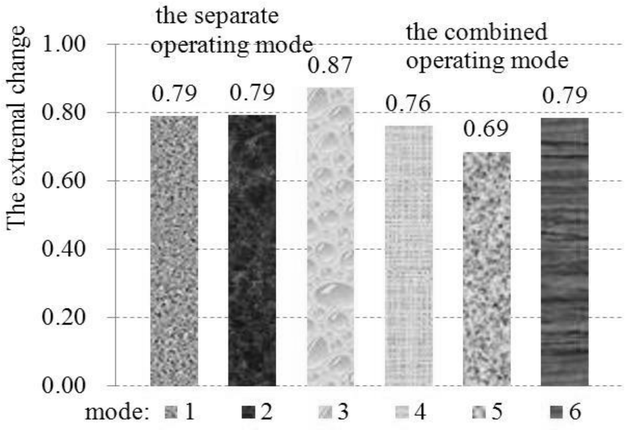

Fig. 6. The extremal change caused by the construction of the Maerdang reservoir

Figure 6 shows the extreme value deviations caused by the construction of the Maerdang reservoir. It can be seen from Fig.6 that the extreme value deviations are relatively small of both separate and combined operating modes, meaning that the extreme river water temperatures hardly change after the construction of the Maerdang reservoir. It can also be seen that whatever the assumptions are, the processes of the river water temperature change have been slowed down after the Maerdang reservoir' construction, however, compared to the combined operating mode, the separate operating mode produces greater influence on extreme value deviations. Still, you can note from Fig.6 that the maximum index of extreme value occurs in flood period when the Maerdang reservoir operates separately while the minimum one occurring in dry period together with the combined operating mode, so conclusions can be drawn that the greatest influence on river water temperature is caused by the combined operating mode during the dry period while the minimal influence caused by the separate operating mode during the dry period.

IV. CONCLUSION

In this study, 3D numerical model has been adopted to simulate the water temperature distribution in the reservoir area. Using the water temperature index evaluation method, three indexes, i.e. baseline deviation, phase deviation and extreme value deviation, as well as 6 operating modes, including the combined operating mode between the Maerdang reservoir and the Ningmute reservoir, are picked to study the river water changing regularity. Through analysis of the simulating results, conclusions are made that: the greatest influence on river water temperature is caused by the combined operating mode during the dry period while the minimal influence caused by the separate operating mode during the flood period; analysis of the index of water temperature deviation give intuitive water temperature changing patterns in different ways. The monthly temperature deviation index, the cold/warm temperature period temperature deviation index and the annual temperature deviation index can be calculated. The index of phase deviation gives the lag effects resulted from the construction of the Maerdang reservoir while the index of extreme valued deviation showing the slowdown effects on the processes of the river water temperature change. In a word, this study can give strong support to the rational development and utilization of the picked reach and researches on the reservoir optimal operation.

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