The influence of time domain on flood season segmentation by the Fisher optimal partition method

yanbin Li
North China University of Water Resources and Electric Power

yubo li (lybacademic@163.com)
North China University of Water Resources and Electric Power

kai feng
North China University of Water Resources and Electric Power

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The influence of time domain on flood season segmentation
by the Fisher optimal partition method

LI Yanbin, LI Yubo, FENG Kai

College of Water Conservancy Engineering, North China University of Water Resources and Electric Power, Zhengzhou 450045, China

Corresponding author: FENG Kai Email: fengk0121@163.com

Abstract: Setting the staged flood limit water level (FLWL) through flood season staging is an important means of fully utilizing reservoir flood resources. The Fisher optimal partition method has been widely used to determine the optimal staging of a flood season. It requires a certain time-domain as the basic unit. This study aimed to analyze the influence of various selected time-domain units on the staging results and to provide a scientific time-domain selection basis for the application of the method in flood season staging. Flood season staging was conducted by taking four specific time-domains: 5, 7, 10, and 15 days as the basic units. The rationality of the flood season staging scheme was tested using the improved Cunderlik method, and the influence of specific time-domains as the basic units in the Fisher optimal partition method on the staging results was evaluated. The results showed the highest relative superiority of 0.9681 for the time-domain unit of 5 d. Therefore, it is recommended that 5 d be used as the time-domain unit. The optimal staging result was determined as June 20 for the first segmentation point and August 20 for the second. According to the results of the staged FLWL compared with a single fixed FLWL, the water level was raised by 5.2 m in the pre-flood season, 0.3 m in the main-flood season, and 3.7 m in the post-flood season. Water
storage increased by 24.628 million m³ during the flood season, effectively alleviating the contradiction between water supply and storage.

Keywords: Flood season segmentation, Fisher optimal partition, Rationality examination time-domain, Flood limited water level.
1 Introduction

As an important natural resource, water is necessary for human survival and provides important support for economic and social progress (Loucks and van Beek 2017). As society has developed, the demand for water resources in various industries and agriculture has increased, and the discrepancy between the supply and demand of water resources is becoming increasingly acute (Tan et al. 2017). Owing to the uneven distribution of rainfall in time and space, it can be difficult to meet the water demand at certain times of the year and to balance the water demand of separate regions. As an important artificial water storage source, reservoirs can effectively improve the uneven temporal and spatial distribution of water resources (Chou and Wu 2013; Guo et al. 2009). To meet the safety requirements of preventing large floods, water resources can only be stored up to a fixed flood limit water level (FLWL) during the flood season (Cheng et al. 2008; Diao and Wang 2011; Ding et al. 2015). However, most reservoirs only prevent small and medium floods, wasting some of the reservoir storage capacity and making it difficult to solve the increasingly prominent problem of conflicting water supply and demand (Chen et al. 2013). Therefore, to improve the reservoir's water storage capacity and fully considering the various characteristics of rainfall and flooding during the flood season, the flood season was divided into several stages to set specific segmented FLWLs without increasing flood control risks. This fully utilizes flood resources during the flood season (Liu et al. 2015) and reduces the pressure of water supply during and after the flood season.
The method for flood season segmentation has undergone gradual development from the qualitative method of causative analysis (Bender and Simonovic 2000; Singh et al. 2005) and further quantitative methods of statistical and fuzzy analysis based on historical storm floods, to the new methods of more refined and rigorous quantification (Song and Wang 2022). The main staging methods can be summarized as follows: (1) The clustering method, which classifies various categories by finding the smallest difference within a class. Mo et al. (2018) considered the effect of climate change, used the Set Pair Analysis Method (SPAM) for flood season segmentation, and determined the staged FLWL. Ju et al. (2020) used an improved fuzzy set analysis method based on the normal distribution theory to stage the flood season of cascade reservoirs downstream of Jinshajiang River. (2) The change-point method, which uses the flood hydrological elements as a time series, based on statistical theory, to find a series of sudden changes and as a division of the time series of excessive and staging points. Liu et al. (2010) used two types of segmentation models that depended on either the annual maximum (AM) and the peaks-over-threshold (POT) sampling, applied the probability change-point analysis technique for flood staging, and used Monte Carlo experiments to evaluate the performance of these models. (3) The ensemble-method approach, which is coupled with various staging methods and combines the advantages of each method to make the flood stage staging results more reasonable. Jiang et al. (2019) used an integrated dynamic fuzzy c-mean method clustering validity function and genetic algorithm, which objectively determined the optimal number of clusters to achieve flood staging. Jiang et al. (2015) used an ensemble-method approach of fuzzy clustering
methods, probability change point analysis, and statistical graph techniques to provide a more reasonable segmentation than the individual methods.

The Fisher optimal partition method is a statistical method for the cluster analysis of ordered samples, which considers multiple factors and maintains the original sample order. It is widely used in flood season staging (Jiang et al. 2019; Tang and Zhang 2018; Wang et al. 2016; Zhou 2022). Most current studies improve Fisher’s optimal partitioning method by assigning different index weights. Yu et al. (2021) compared commonly used indicator weighting algorithms and concluded that the weights have only minor influence on the staging results. Therefore, the study of the indicator weights for the Fisher optimal partition method is not significant. However, the Fisher optimal partition method in flood staging uses a certain time-domain as the basic unit for cluster optimization. The time domains generally chosen are the 5-day and the 10-day domains. Xu and Niu (2019) used the Fisher optimal partition method with 5-day and 10-day time units in the flood staging of Zhangjiazhuaung reservoir and found that the delay of the main flood season became longer by 15 days when using the 5-day time unit. This was thought to be the reason that the gap within the sample class was smaller and more refined when the 5-day time unit was used. This judgment is highly subjective and lacks a basis for quantitative scientific judgment.

In this study, the time-domains of 5, 7, 10, and 15 d were used as time units, and four flood staging schemes were obtained from the Fisher optimal partition method through an example investigation of flood staging for the JianGang Reservoir. The ra-
tionality of the staging results in specific time-domains was evaluated using the ration-
ality test method (Chen et al. 2015), and the influence of the staging results was ana-
lyzed. The optimal staging scheme was determined, the staged FLWL was extrapolated,
and the water supply benefits of the staged FLWL were evaluated and compared with
those of a single fixed FLWL. These research ideas and methods provide a reference
base for research and application of similar problems.

2 Methods and Principles

2.1 Fisher optimal partition method

2.1.1 Concept

The Fisher optimal segmentation method is used to cluster a sequence of ordered
time samples, and is based on the minimum square sum of the sample total deviation,
with the smallest difference within the class and the maximum difference between the
classes (Tang and Zhang 2018). As a cluster analysis method for ordered samples, it
allows for the consideration of several factor indicators and the determination of the
optimal number of segments and flood season segmentation results according to the
defined objective function, without destroying the original order.

2.1.2 Steps of calculation

(1) Processing the data. Based on n samples arranged in a certain order, each with
m factor indicators, an ordered sample, and a relationship matrix $X_{ij}$ (where $i = 1, 2, \ldots, n$, and $j = 1, 2, \ldots, m$) constructed using multi-factor indicators, $X$. The physical quanti-
ties of each indicator are of different magnitudes and cannot be compared directly.
Therefore, it is necessary to transform the characteristic values of the indicators so that they are dimensionless, then obtain the standardized characteristic matrix $X'$.

$$x'_{ij} = \frac{x_{ij} - x_{\text{min},j}}{x_{\text{max},j} - x_{\text{min},j}},$$  \hspace{1cm} (1)

where $X_{ij}'$ is the characteristic value of the index after normalization, and $X_{\text{max},j}$ and $X_{\text{min},j}$ are the maximum and minimum values of $X_{ij}$ in the $j$th index, respectively.

(2) Determining the objective weight by entropy weight. The entropy weighting method determines the degree of disorder and information effectiveness of information by calculating the information entropy based on the information of influencing factors. The positive correlation between the entropy value and the effective information provided by the index value also indicates the level of the weight value (Zhong et al. 2022). It is calculated using the following equations (Zou et al. 2006). Based on the determined relationship matrix $X$, it was normalized to calculate the index information entropy $S_j$.

$$S_j = -\frac{1}{\ln n} \sum_{i=1}^{n} x'_{ij} \ln \left( \frac{x'_{ij}}{x_j} \right),$$  \hspace{1cm} (2)

$$x_j = \sum_{i=1}^{n} x'_{ij},$$  \hspace{1cm} (3)

where $i = 1, 2, ..., n$, $j = 1, 2, ..., m$, $S_j$ is the information entropy of the $j$th influencing factor, and $X_j$ is the sum of the $n$ information values of the $j$th factor. The weights of the influencing factors were calculated.

$$\omega_j = \frac{1 - s_j}{m - \sum_{j=1}^{m} s_j} \left( 0 \leq \omega_j \leq 1, \sum_{j=1}^{m} \omega_j = 1 \right).$$  \hspace{1cm} (4)
Each indicator is assigned specific weight coefficients $\omega_1, \omega_2, \cdots \omega_m$ according to its importance to the sample classification, and the matrix of multi-indicator eigenvalues can be transformed into a one-dimensional eigenvalue vector $Y$ after the weighted average, as follows:

$$
Y = \left( \begin{array}{c} y'_1 \\ \vdots \\ y'_{mn} \end{array} \right) = \left( \begin{array}{c} x'_{11} \\ \vdots \\ x'_1 \\ \vdots \\ \vdots \\ x'_{nm} \end{array} \right) \left( \begin{array}{c} \omega'_1 \\ \vdots \\ \omega'_{n} \end{array} \right),
$$

where $Y$ is used as the initial vector after the weighting assignment for which the sample sequence is segmented.

(3) Defining the class diameter. The degree of difference among classes is expressed by the class diameter. The smaller the difference among the samples, the smaller is the class diameter. Suppose the class $P = y_i, y_{i+1}, \ldots, y_j (j > i)$; then, the average value of class $P$ can be found as follows:

$$
\bar{y}_P = \frac{1}{j-i+1} \sum_{\alpha=i}^{j} y_{\alpha}.
$$

Assuming that $D(i,j)$ denotes the class diameter of class $P$, $D(i,j)$ can be determined from the mean $\bar{y}_P$ of class $P$.

$$
D(i,j) = \sum_{\alpha=i}^{j} (y_{\alpha} - \bar{y}_P)^2.
$$

(4) Defining the objective function. If $n$ ordered time samples are divided into $k$ classes, $B'(n,k)$ is defined as one of the classification methods, and its computational formula is expressed as follows:

$$
B'(n,k) = \sum_{\alpha=1}^{k} D(i_{\alpha}, t_{\alpha+1} - 1),
$$
where the minimum value of \( B'(n,k) \) is the optimal classification method. Therefore, the objective function \( B(n,k) \) is defined as follows:

\[
B(n, k) = \min B'(n, k) = \min \sum_{\alpha=1}^{k} D(i_{\alpha}, i_{\alpha+1} - 1). \tag{9}
\]

The calculation of \( B(n,k) \) has the following recursive process.

\( k = 2, B(n, 2) = \min_{2 \leq i \leq n} \{D(1, i - 1) + D(i, n)\} \). \hspace{1cm} \tag{10} \\
\( k > 2, B(n, k) = \min_{k \leq i \leq n} \{D(i - 1, k - 1) + D(i, n)\} \). \hspace{1cm} \tag{11}

(5) Determining the optimal segmentation. When objective function \( B(n,k) \) is found, the ordered sample can be divided into \( k \) classes. To determine the optimal number of segments, a graph of the objective function \( B(n,k) \) and the number of segments \( k \) is constructed, where the inflection is the optimal number of segments. The degree of change in the slope \( \gamma(k) \) of the graphed curve is determined. We calculated \( \gamma(k) \) using the following formula:

\[
\gamma(k) = |B(n, k) - B(n, k - 1)|. \tag{12}
\]

Then, the graph of \( \gamma(k) \) and the number of segments \( k \) were plotted, where the maximum position was at the maximum change: that is, the optimal number of segments.

2.2 Reasonable analysis

Chen et al. (2015) improved the Cunderlik et al. (2004) method of dividing abundance and depletion by month for the whole year, and introduced a fuzzy superiority function to quantitatively evaluate the rationality of flood staging. A more quantitative and accurate evaluation of staging results (Chen et al. 2019; Liu et al. 2010; Sun et al.
2020; Zhou 2022) is widely used compared to the results of multiple staging methods. Jun et al. (2021) used the modified Cunderlik method for reasonableness analysis based on rainfall data when classifying flood and non-flood periods. Therefore, this study analyzed the reasonableness of the staging results of basic units in various time-domains based on daily rainfall data at the JianGang Reservoir from 1970-2017. The basic calculation steps were to: (1) Assume that the probability of precipitation occurring on any day during the flood period obeyed a uniform distribution. (2) Determine the upper and lower frequency values of the uniform distribution corresponding to the rainfall causing the flood, by random selection. (3) Determine the relative frequency values of the rainfall data for the JianGang Reservoir over 48 years using the nonparametric bootstrap sampling method. (4) Calculate the generalized distance to find the relative affiliation. (5) Derive the fuzzy relative superiority value for comparison of various staging schemes. See Chen et al. (2015) for the specific formulas and steps.

2.3 Calculation of the staged FLWL

The design flood process method was used for each phase in accordance with the maximum value of the intertemporal sampling method. The cumulative empirical frequency of each phase of the flood peak series was calculated using the P-III type frequency curve. Then, the design flood of each phase was determined. According to the typical flood process, various initial and diversion water levels were formulated, and the flood regulation calculation was performed according to the reservoir capacity and discharge relationship of the reservoir water level using the following formula:

$$\frac{Q_1 + Q_2}{2} \Delta t - \frac{q_1 + q_2}{2} \Delta t = V_1 - V_2 \quad ,$$  (13)
where \( q = f_1(Z); \ V = f_2(Z); \ Q_1 \) and \( Q_2 \) indicate the reservoir inflow at the beginning and end of the period (m³/s); \( q_1 \) and \( q_2 \) are the discharge flows at the beginning and end of the period (m³/s), respectively; \( V_1 \) and \( V_2 \) are the water storage capacities of the reservoir at the beginning and end of the period (m³); \( \Delta t \) is the calculation period (s); and \( Z \) is the water level (m).

According to the results of the flood diversion calculation, the FLWL of each stage was determined by selecting the highest initial water level that met the flood control requirements in each stage.

3. Study Area and Data

The JianGang Reservoir is located upstream of the Jialu River in the Shaying River system of the Huai River Basin (Fig. 1). The dam is located west of JianGang Village in Zhengzhou City, with a controlled drainage area of 113 km² and a total reservoir capacity of 60,704,100 m³. The area is near the Yellow River Basin, which is at the edge of China’s warm temperate semi-humid monsoon climate region. It has four distinct seasons controlled by Pacific subtropical high pressure in summer and autumn, with common southeast winds and hot, rainy conditions. It is controlled by Siberian and Mongolian high pressure systems in winter and spring, with prevailing northwest winds, a dry climate, and little rain. Precipitation is unevenly distributed within the year and between years, with an average annual rainfall of approximately 640 mm. Approximately 70% of the annual rainfall is concentrated in the flood season of July, August, and September, with storms occurring mostly in July and August.
The basic information used in this study was the daily precipitation data from 1970 to 2017 at JianGang Reservoir. Rainfall was mainly concentrated from July to September, and the study period was chosen from June 1 to September 30 to encompass the entire flood season. Based on the independence and seasonal screening of rainfall indicators (Jun et al. 2021), the multi-year average maximum 1-day rainfall (Q1), multi-year average maximum rainfall day (Q2), and multi-year average precipitation (CV) values were selected as indicators to construct the characteristic matrix.

4. Results and Discussion

4.1 Flood season segmentation

4.1.1 Entropy weighting method to calculate weights

Taking 5 d as the basic unit in the time-domain, the feature matrix was normalized using Equation (1) and based on the feature matrix data. Then, the weights of the three indicators were calculated by the entropy weighting method using Equations (2), (3), and (4). The resulting weight values of Q1, Q2, and CV were $\omega_{5d} = (0.3238, 0.2124, 0.4638)$.

4.1.2 Fisher optimal segmentation

The requested weight value $\omega$, was substituted into formula (5) to obtain $Y$. Then, according to Equations (6) and (7), the class diameter $D(i,j)$ was obtained according to $D(i,j)$ through formulas (10) and (11) to calculate the objective function $B(n,k)$, and through Equation (12) to find the optimal segmentation node. The results are shown in Table 1.
The graphs of the objective function $B(n,k)$ versus the number of segments $k$, and $\gamma(k)$ versus the number of segments $k$ are shown in Figure 2.

Figure 2 shows that $B(n,k)$ gradually decreases with an increase in the number of segments $k$. There is a clear inflection at $k = 3$, which corresponds to the maximum of $\gamma(k)$. Therefore, the optimal number of segments (3) was determined. According to Table 2, the segmentation results were June 1 to June 20 for the pre-flood period, June 21 to August 20 for the main-flood period, and August 21 to September 30 for the post-flood period.

As with using 5 d as the basic unit of the time-domain, the same feature matrix was constructed by selecting the same feature indicators with 7, 10, and 15 d as the basic units of the time-domain. The corresponding weight values were obtained by the entropy weighting method as $\omega_{7d} = (0.3888, 3571, 0.2541)$, $\omega_{10d} = (0.3227, 0.3792, 0.2981)$, and $\omega_{15d} = (0.2757, 0.3674, 0.3568)$. The weights were substituted into Equation (5), and the corresponding intraclass diameter $D(i,j)$ and objective function $B(n,k)$ were derived in turn. The graphs of the objective function $B(n,k)$ versus the number of segments $k$ and $\gamma(k)$ versus the number of segments $k$ were plotted in Figures 3, 4, and 5.

As Figures 2-5 show, $\gamma(k)$ is maximum at $k = 3$. Therefore, the optimal number of segments was taken as three, and the flood staging results of four different time domains were obtained according to the objective function $B(n,k)$, as shown in Table 2.
4.2 Reasonable analysis

The theoretical frequency curves of the confidence intervals of the four schemes were obtained according to the steps determined by the upper and lower bounds of the evenly distributed confidence interval, as shown on Figure 6.

Because the data used in this study are rainfall data from 1970 to 2017, the results of fitting were obtained by fitting $N = 48$ years for 5 d $y_{\text{up}} = 0.4575$, $y_{\text{lower}} = 0.1959$; 7 d $y_{\text{up}} = 0.4667$, $y_{\text{lower}} = 0.2222$; 10 d $y_{\text{up}} = 0.4621$, $y_{\text{lower}} = 0.1906$; and 15 d $y_{\text{up}} = 0.4310$, $y_{\text{lower}} = 0.1544$. According to the frequency values of the upper and lower limits, the relative membership of each stage was calculated, and the relative superiority of specific time-domain schemes was obtained according to the relative favorability formula, as shown in Figure 7.

According to the relative genus preference relationship of the four schemes, the genus degree of the 5-day basic unit staging was 0.9681, followed by the 10-day basic unit staging at 0.9331. The fuzzy relative superiority of both schemes exceeded 0.9, indicating an acceptable staging scheme. Therefore, it is best to use 5 d as the basic unit staging scheme for the Fisher optimal partition method. However, the fuzzy relative superiority of the 10 d scheme was comparable to 5 d scheme, so it can also be applied to flood staging.

According to Table 2, there are three first-stage nodes of the pre-flood and main-flood seasons: June 15, 20, and 21. There are also three second-stage nodes of the main- and post-flood periods: August 14, 15, and 20. The fuzzy relative superiority of 24
schemes fixed with 3 first-staging points and a series of second-staging point combinations with a gradient from August 14 to August 21 were calculated as shown in Figure 8. The fuzzy relative superiority of the three second-staging point and a series of first-staging point combinations with a series of June 14 to June 21 gradients was fixed. The results are shown in Figure 9.

Figures 8 and 9 show that among the three schemes with fixed first segmentation points, all have August 20 as the better second segmentation point. The scheme is optimal when the first staging node is June 20, with a relative superiority of 0.979. Among the three schemes with fixed second segmentation points, all have June 20 as the better first segmentation point, and the scheme is optimal when the second segmentation point is August 20, with a relative superiority of 0.997. In summary, the staging scheme was determined to be optimal with June 20 as the first segmentation point and August 20 as the second segmentation point. The same staging results of the Fisher optimal partition method were obtained with 5 d and 10 d as the basic units. The results demonstrate that the Fisher optimal partition method can be used for flood staging with 5 d and 10 d as the basic units, and the staging scheme is optimal with 5 d as the basic unit. However, this was only marginally superior to the 10 d unit. Using the staging scheme with other time-domains as the basic unit is not recommended.

4.3 FLWL determination and benefit analysis

Table 3 shows peak flow information for the reservoir from 1970 to 2017. The hydrological series was composed of sample series, compiled according to the annual
maximum method, to form a sample capacity of 48 peak flows for each phase. Considering the maximum of the phase for appropriate intertemporal sampling, we used the mathematical expectation formula to calculate the cumulative empirical frequency of each phase of the peak flow series. We used the current hydrological frequency calculation method and the appropriate line method to derive the corresponding peak flow of the stage of the 100-year (1%) design standard and 5000-year (0.02%) calibration standard.

Based on the principle of typical flood selection, a typical flood process was selected from the measured data, as shown in Figure 10. The flood process of August 6, 1975 was selected from the measured flood data of the Tsimshatsui station as a typical flood process for projecting 100-year design standards and 5000-year calibration standard flood processes. The corresponding typical flood was magnified using the same method to derive the design flood process.

Under the premise of ensuring flood control safety, the design flood level of 153.01 m and the calibrated flood level of 156.47 m for the JianGang Reservoir were used as the control values of reservoir flood control scheduling. Various initial water levels were formulated according to a typical flood process, and the flood regulation calculation was performed according to the relationship between the reservoir water level and the discharge relationship. The Matlab program was used to calculate the highest water level that did not exceed the flood control standard (Table 4).
Table 4 shows that during the pre-flood season, when the calibration flood occurs and the initial water level is 150.3 m, the maximum water level reaches 156.52 m, exceeding the checked flood level of 156.47 m. When the design flood occurs, the flood diversion calculation is conducted with the same initial water level, and the all maximum water levels are less than the design flood level of 153.01. In the main-flood season, through the flood regulation calculus, when the calibration flood occurs and the initial water level is 145.4, the maximum water level reaches 156.47 m, which is equal to the checked flood level. When the design flood occurs, the maximum water level of the calculation results is also less than the design flood level of 153.01. In the post-flood season, when the calibration water level occurs and the initial water level is 148.8 m, the maximum water level reaches 156.48 m, exceeding the checked flood level of 156.47 m. When the design flood occurs, the maximum water level of the calculus result is also less than the design flood level of 153.01 m. Therefore, to ensure the safety of the reservoir, the flood limit water level should be set to 150.2 m in the pre-flood season, 145.3 m in the main-flood season, and 148.7 m in the post-flood season.

By staging the flood season of the JianGang Reservoir and setting specific flood limit water levels for each stage, compared with the original single flood limit water level of 145 m, the water levels were raised by 5.2 m for the pre-flood season, 0.3 m for the main-flood season, and 3.7 m for the post-flood season. Under the premise of not affecting the safety of flood control, the water storage capacities were increased by 14.39 million m³ in the pre-flood season, 0.66 million m³ in the main-flood season, and 9.578 million m³ in the post-flood season. Therefore, the total increase in water storage
across the whole flood season could reach a maximum of 24.628 million m³. Compared with the single flood limit water level, the phased flood limit water level substantially increased the water storage across the flood season.

5. Conclusion

This study aimed to analyze the influence of various selected time-domain units on the staging results and to provide a scientific time-domain selection basis for the application of the Fisher optimal partition method in flood season staging. In this study, we selected the JianGang Reservoir as the research object and examined specific time-domain basic units used in flood season staging by the Fisher optimal partition method. We used 5, 7, 10, and 15 d time-domain basic units for flood season staging and compared them by the rationality analysis method. The research conclusions are as follows:

(1) The flood period was staged using the Fisher optimal partition method for specific time-domains. The results of the 5-day and 10-day staging were the same. The pre-flood season was from June 1 to June 20, the main-flood season from June 21 to August 20, and the post-flood season from August 21 to September 30. The first segmentation point of 15-day unit was 5 days earlier than June 20, the first segmentation point of 7-day unit was the same, and the second segmentation point of 7-day and 15-day staging was nearly 5 days earlier than August 20.

(2) Through rationality analysis, the staged schemes of specific time-domains were compared. It was concluded that the relative superiority of the 5-day basic unit staging
reached 0.9681, followed by 0.9331 for the 10-day unit. There were only marginal differences in superiority between the 5-day and 10-day units. However, the staging scheme for the other time-domains was poor. By fixing the first and second staging nodes, we compared the staged schemes to determine the best staging scheme, using June 20 as the first segmentation point and August 20 as the second segmentation point. The results show that when the Fisher optimal partition method was used for staging, the 5-day or 10-day units could be used as the basic unit for flood staging. The 5-day unit was the optimal basic unit staging scheme. Using other time domains as the basic unit for staging is not recommended.

(3) Through the flood season stage, the staged flood limit water level was set for the flood season of JianGang Reservoir, and the FLWL was determined to be 150.2 m in the pre-flood season, 145.3 m in the main-flood season, and 148.7 m in the post-flood season, compared with the single FLWL of 145 m. The pre-flood season FLWL was raised by 5.2 m, the main-flood season by 0.3 m, and the post-flood season by 3.7 m. Water storage increased by 24.628 million m³ throughout the flood season, substantially alleviating the contradiction between the supply and demand of water resources during the flood season.

**Author Contributions**
The study conception and design Contributed by Yanbin Li. The first draft of the manuscript was written and the computer code and supporting algorithms was implemented by Yubo Li. Material preparation, data collection and analysis were performed by Kai Feng. All authors read and approved the final manuscript.

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**Data Availability**

The data generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations**

**Ethical Approval**

The authors confirm that this article is original research and has not been published or presented previously in any journal or conference in any language (in whole or in part).

**Consent to Participate**

All authors gave explicit consent to participate in this study.
Consent to Publish

The authors agree to publish in the journal.

Competing Interests

The authors declare no financial and personal relationships with other people or organizations that can inappropriately influence our work.

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Figure 1

Map of the JianGang reservoir
Figure 2

Relationship of the 5-day time-domain between $B(n,k)$, $\gamma(k)$, and $k$
Figure 3

Relationship between $B(n,k)$, $\gamma(k)$, and $k$ for the 7 d time domain
Figure 4

Relationship between $B(n,k)$, $\gamma(k)$, and $k$ for the 10 d time domain
Figure 5

Relationship between $B(n,k)$, $\gamma(k)$, and $k$ for the 15 d time domain
Figure 6

Graphs of relative frequency confidence for four time-domains: (a) 5 d; (b) 7 d; (c) 10 d; and (d) 15 d
Figure 7

Relative superiority versus time-domain scheme
Figure 8

First segmentation points
Figure 9

Second segmentation points
Figure 10

Typical flood hydrograph

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