Uncertainty analysis of flood control design under multiple floods

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Abstract

The conventional flood control design analysis usually focuses on a specific aspect like flood peak discharge or the volume of flood, with the development of technology, hydrological analysis tends to be multi-dimensions research. The multivariate frequency analysis of a flood has been widely investigated, while there is lack of literatures about flood control design under multiple floods. In this study, taking the Guiping Shipping Hub as a study case, a Copula-based approach is proposed to investigate the flood control design under multiple floods, comparison between the proposed method and conventional approach is investigated, the sampling uncertainty is analyzed. The results indicate that (1) the joint distribution of main and tributary floods is modeled by Clayton Copula with PE3 as the best-fit marginal distributions. The proposed Flood Control return period (FC-RP) can describe the different role of main and tributary floods in flood control design. (2) flood combinations uncertainty analysis indicates that the uncertainty of the joint design combinations under the effect of multiple floods decreases with the increase of sample size n, but increases with the increase of the design return period. (3) the 95% confidence interval and standard deviation of the design value of flood control design water level calculated by Flood Control RP is smaller than that of OR RP, which means the Flood Control RP can reduce the uncertainty of flood control design under the condition of multiple

floods.

Keywords: Multiple floods, Copula, Flood control design water level, Return period, Uncertainty analysis

1. Introduction

The determination of flood control design water level has important engineering significance for the safe operation of water conservancy projects (Alila & Mtiraoui, 2002; Ren, Deng & Feng, 2016). For conventional hydraulic engineering flood control design, usually only focus on a specific aspect of a single flood, using the same magnification method to calculate the design flood, or directly use the flood peak discharge as the design flood, then deducing design water level based on design flood. However, Chenbana and Quarda (2011) considered that univariate frequency analysis is not comprehensive enough, especially in hydraulic event return period design. Therefore, the past decades, multivariate hydrological analysis has been widely investigated by applying the Copula function due to its flexible and convenient (Favre, et al; 2004; Salvadori & Michele, 2004; Shiau, 2006; Zhang & Singh, 2007). The Copula function has widely applied in the hydrological multivariate risk analysis such as peak and volume of flood (Duan, Mei & Zhang, 2016; Li, et al, 2013; Sraj, Bezak, & Brilly, 2015; Zhang & Singh, 2007), duration and intensity of drought (Abdi, et al, 2016; Mieakbari, Ganji, & Fallah, 2010; Shiau & Modarres, 2009; Xu, et al; 2015) and the combination of rain and tide in the coastal area (Lian, Xu, & Ma, 2013; Xu, et al; 2014; Tu, et al, 2017), etc.

The multivariate analysis of single flood has been extensively studied (Reddy & Ganguli, 2012), but the frequency analysis and flood control design under multiple floods is still questionable. So far as we know, there is no suitable method to calculate the design level of flood control under multiple floods, for example, some water conservancy projects built at the intersection of main and tributary estuaries directly use the combination of experience to calculate the design water level, which is lack of scientific and reasonable analysis. It is recommended that the same as the bivariate frequency analysis of a single flood, the flood control design under the combination of main and tributary floods can also be considered as bivariate flood risk analysis. For a given design return frequency *p*, there are numerous combinations of variates (Mediero, Jiménez, & Garrote, 2010; Yin, et al, 2017), whether it is traditional *RP* or Kendall RP. Furthermore, countless different design flood combinations corresponding to the same design return period have different threats to hydraulic projects. Thus, it remains to be questioned which flood combination is adopted as the design combination.

As for bivariate frequency analysis, the uncertainty analysis has become more important in recent years (Rahimi, Saghafian, & Banihashemi, 2020). In bivariable hydrological analysis, there are two main causes for the calculation uncertainty, one is due to the marginal distribution selection, the other is sampling uncertainty, which is the more important one in uncertainty analysis (Serinaldi, & Kilsby, 2015; Zhang, Xiao, & Singh, 2015). To qualitatively analyze the effect of uncertainty, Serinaldif (2013) and Dung (2015) proposed three algorithms and non-parameter procedure respectively to investigated the sampling uncertainty, Pham-Gia (2001), Liu (2010) and Yin (2018) applied four different indicators to estimate the sampling uncertainty of bivariate hydrological analysis. As mentioned above, the main and tributary floods can be considered as bivariate hydrological event, it is necessary to investigate the uncertainty of flood control design water level under the combination action of multiple floods, especially when applying the different return period for flood control design.

In this paper, a risk analysis model for the main and tributary floods is established by applying the bivariate Copula, the Flood Control RP is proposed to investigate the flood control water level under the combined action of main and tributary floods. The Flood Control RP is compared with the *OR* and *AND* return periods, the flood combinations uncertainty due to the sample sizes *n* of main and tributary floods is assessed, and the sampling uncertainty of the flood control design water level calculated by the proposed Flood Control RP and *OR* RP is also investigated.

2. Theory and method

2.1 Copula theory

Taking a bivariate case as an example, X and Y are two continuous random variables, $F(x)$ and $F(y)$ are cumulative marginal distribution functions of the variables X and Y respectively. According to Sklar (1959), the two marginal functions can be integrated by a Copula function, that is,

$$F_{XY}(x,y)=C\left[F(x),F(y)\right]=C\left[u,v;\theta\right] \tag{1}$$

where $F_{XY}(x,y)$ is the joint distribution function of X and Y, $C(u,v;\theta)$ is a bivariate Copula function with a parameter θ.

In general, there are Ellipse Copulas (Fang, Fang, & Kotz, 2002), Plackett Copulas (Plackett, 1965) and Archimedean Copulas three main types of bivariate Copula functions that are commonly used in flood or drought risk analyze, in which the Archimedean Copulas are the most widely used due to its simple structure and easy calculation (Brahimi, Chebana, & Necir, 2011; Mou, et al, 2018; Nelsen, 2000). In this study, four commonly used Archimedean Copulas, Clayton, Frank, Gumbel-Hougaard (GH) and Ali-Mikhail-Haq (AMH) Copulas. The parameter θ is calculated by using the Kendall correlation method for the simple relationship between θ and Kendall correlation coefficient τ.

Table1. Four commonly used Archimedean Copula functions

Copula type	Bivariate Copula function
Clayton	$C(u,v)=(u^{-\theta}+v^{-\theta}-1)^{(-1/\theta)};\theta\in(0,\infty)$
Frank	$C(u,v)=\frac{-1}{\theta}\ln\left\{1+\frac{[\exp(-\theta u)-1][\exp(-\theta v)-1]}{\exp(-\theta)-1}\right\},\theta\in R$
GH	$C(u,v)=\exp\left\{-[(-lnu)^{\theta}+(-lnv)^{\theta}]^{\frac{1}{\theta}}\right\};\theta\in[1,\infty]$
AMH	$C(u,v)=\frac{uv}{1-\theta(1-u)(1-v)},\theta\in[-1,1]$

For bivariate hydrological events of main and tributary floods, *OR* recurrence period refers to the recurrence period of at least one of the main stream or tributary floods that is greater than the design flood. *AND* RP refers to the recurrence period of the main stream or tributary floods that are greater than the specified flood at the same time. The *OR* and *AND* RPs can be described as follow,

$$T_O = \frac{1}{P(X > x \cup Y > y)} = \frac{1}{1 - C(u, v)} \tag{2}$$

$$T_A = \frac{1}{P(X > x \cap Y > y)} = \frac{1}{1 - u - v + C(u, v)} \tag{3}$$

According to the calculation of the joint recurrence period under multi-variable conditions, for any given design recurrence period, whether it is *OR* or *AND* RP there are countless combinations of variables corresponding to it. Also, in this study, with a given design RP *T*, there are numerous main and tributary floods combinations, the risks brought by different flood combinations are also different. Furthermore, the flood control design water levels calculated by different flood design combinations through flood control calculations are also different, this leads to inconsistent flood control capabilities of water conservancy projects, and there is no one-to-one correspondence between the design flood return period and the design flood combination. In fact, the threat caused by the flood is not only related to the characteristics of the flood itself, but also to the characteristics of the flood discharge interface.

The result of the coupling effect of floods and different flood boundary conditions can produce a variety of flood control characteristic parameters, such as flood control levels of floodgates and dams, and flood control storage capacity, the difference between the water depth after the jump of the stilling pool and the water depth of the channel, and the flood surface of the channel. In this paper, the average interval time when the flood control parameter f determined by different flood combinations exceeds its specific flood control parameter F is defined as the Flood Control RP. The flood control design water level z under the combination of main and tributary floods is considered as the flood control parameter, thus, the dangerous events can be described as,

$$E_{X,Y}^{F} = \{H(x,y) > Z\} \tag{4}$$

where x and y are main and tributary floods respectively, H is a method for flood regulation calculation, Z is a design water level of flood control under the condition of specific return period.

The recurrence period corresponding to $E_{X,Y}^{F}$ is the Flood Control RP, which is,

$$T_F = \frac{1}{P\{H(x,y) > Z\}} = \frac{1}{1 - F_Z(z)} \tag{5}$$

where $F_Z(z)$ is cumulative distribution function of flood control water level.

In multivariate hydrological analysis, the most likely combination is the most concerned, that is,

$$(u_m, v_m) = \arg\max f(u,v) \tag{6}$$

$$f(u,v) = c(u,v) f(x) f(y) \tag{7}$$

where $c(u,v)$ is the joint distribution joint distribution probability density function, $f(x)$ and $f(y)$ are the marginal distribution probability density functions of main and tribute flood, respectively.

2.2 Method for flood regulation calculation

Figure 1 shows the relationship between the flow of Guigang station and the flow of Dahuangjiangkou station and the bottom water level of Guiping Shipping hub dam. According to the relationship mentioned above, an approach for flood regulation calculation is applied to calculate the design flood level of the shipping hub, that is,

$$Q = \sigma\varepsilon MB\sqrt{2g}H_0^{\frac{3}{2}} \tag{8}$$

where σ is submerged coefficient, ε is lateral shrinkage coefficient, $M = \sqrt{2g}\,m$, in which m is discharge coefficient, B is the net width of a single gate, m, H_0 is the total hydraulic head of wire crest.

Fig.1 Traffic volume of Guigang Railvay Station: Natural water level relationship of runoff to dam site at Dahuangjiangkou Station

2.3 Uncertainty measurement

There are several approaches had been proposed to quantify the uncertainty caused by the limitation of records. Among them, Pham-Gia (2001), Liu (2010) and Yin (2018) applied Horizontal average offset (D_X), vertical average offset (D_Y), area of confidence interval (S), and average Euclidean distance (d) four indicators to quantitatively calculate uncertainty. In this paper, D_X and D_Y are the estimated deviations between the main and tributary flood discharges and the design value derived from the actual observation sample sequence respectively. S and d are used to measure the spatial distance between the design value point data and the actual measured sample series design value. The smaller the index value, the smaller the uncertainty. Confidence interval area is calculated by using the ContourSizes Functions of R program, and the other three metrics are depicted as follow,

$$D(X) = \frac{1}{N}\sum_{i=1}^{N}\left|x_{Ti} - \hat{x}_T\right|, \quad D(Y) = \frac{1}{N}\sum_{i=1}^{N}\left|y_{Ti} - \hat{y}_T\right| \tag{9}$$

$$d = \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left(x_{Ti} - \hat{x}_T\right)^2 + \left(y_{Ti} - \hat{y}_T\right)^2} \tag{10}$$

where N is the number of repeated samplings, which is taken as 1000 in this paper, $(\hat{x}_T, \hat{y}_T)$ is the most likely design combination value of the joint recovery period of the measured sample sequence

2.4 Steps for flood control design water level and sampling uncertainty analysis

In this study, Monte Carlo simulation method is used to analyze the influence of sampling uncertainty on the design value of flood prevention level of sluice under the action of main and tributary flood. The specific steps to calculate the flood control design water level are,

1) Determining the optimal marginal distribution u, v of the main and tributary floods based on the original data and the optimal distribution model $C(u,v)$.
2) Generate two random numbers n_1 and n_2 at (0,1), let $n_1 = u$, conditional probability $n_2 = C(v|u) = \frac{\partial}{\partial v}C(u,v)$, and solve a set of related relations u and v according to the conditional probability.
3) Converting the random variables u and v into the main and tributary flood X and Y according to the marginal distribution; a flood control design water level Z is obtained after flood regulation calculation.
4) Repeat steps (1)~(3) N times to get N flood control water levels Z, then sort the flood control water levels Z, according $P(Z > z) = 1/T$ to calculate the flood control design water level under the combined action of main and tributary floods with a given T.

The specific steps to calculate the sampling uncertainty under the combined action of main and tributary floods are as follows:

1) The same as the step (1) above,
2) Based on the optimal Copula function, the random variables u and v with a sample size n are simulated by the conditional probability $C(v|u) = \frac{\partial}{\partial v}C(u,v)$, converting the random variables u and v into the main and tributary flood X and Y according to the marginal distribution.
3) Repeat step (2) N times to get N main and tributary flood X and Y combinations with sample size n, and N Copula function parameter θ.

4) For a given *OR* return period, N most likely combinations (X_m, Y_m) is obtained by using the equations
5) Calculating the N most likely combinations by using the Kernel density estimation method to obtain the $(1-\alpha)$ confidence interval area given a certain significance level α.
6) Perform flood regulation calculations on the N most likely combinations flood combinations (X_m, Y_m), and obtain N flood control design water levels $z_{¿}$.

3. Case study

The proposed methodology is used to investigate the uncertainty of the design flood level of the Guiping Shipping Hub Project. As shown in Figure 1, the project is located at the Yujiang River section at the intersection of Yujiang and Qianjiang rivers in Guiping City in the West River Basin of the Pearl River. The engineering is mainly composed of shipping lock, overflow dam and sluice, in which the length of the overflow dam is 296m, the width of the total overflow surface is 238m, 17 holes are set to discharge, the net width of the mouth is 14m, and the height of the weir crest is 21m. The design recurrence period of the sluice of Guiping Shipping Hub is once every 100 years, and the design flood level is 43.48m, obtained after flood regulation calculation by using the combinations of the flood peak flow with the recurrence period of 100 years with 0.2 times the flood peak value of Dahuangjiagnkou station.

In this paper, the flood data from 1953 to 2010 are collected from Guigang hydrological station in the upper reaches of the Yujiang river, and the Dahuangjiangkou station in the lower reaches of the main stream. The sampling data collected from Guigang hydrological station is defined as Y series, subtract the measured sample data from Guigang Station with the measured data from Dajingjiangkou Station as the main stream flow series X.

Figure 2 Overview of the study area and location map of Guiping Shipping Hub

4. Result and discussion

4.1 Selection of marginal distribution and Copula distribution

In this paper, the marginal distributions are depicted by three common-used distribution functions namely Pearson type III (PE3), Generalized Extreme Value (GEV) and Weibull. The parameters of marginal distributions are calculating by using the Moment estimation, the *K-S Test* is applied to examine the degree of fitting of the sample theoretical distribution and empirical distribution. Other two evaluation method *AIC* and *RMSE* approach are also being used to select the best-fit marginal distribution of main and tributary flood. The critical value of the k-s test is 0.179, all the marginal distribution shown in Table 1 pass the k-s test. According to the criterion of the minimum function of the evaluation index is optimal, both of main and tributary flood are best modelled by PE3 distribution.

Table1 selection of marginal distribution

Distribution	*Dahuangjiangkou Station*			*Guigang Station*		
	K-S	*AIC*	*RMSE*	*K-S*	*AIC*	*RMSE*
PE3	0.084	-392.110	0.030	0.096	-407.373	0.028
GEV	0.101	-376.671	0.032	0.103	-388.301	0.033
Weibull	0.108	-389.122	0.033	0.110	-375.367	0.037

Four common-used Archimedean Copulas G-H Copula, Clayton Copula, Frank Copula and A-M-H Copula are applied to model the joint distribution of main and tributary floods. The parameters of above Copula functions and the function fitness evaluation results are shown in Table 2. According to the results, the Clayton Copula is selected as the best-fit function to model the main and tributary floods for its minimal RMSE and AIC values.

Table2 Copula function fitness evaluation result

Copula function	Parameter θ	*RMSE*	*AIC*
G-H Copula	1.189	0.055	-334.261
Clayton Copula	0.377	0.050	-346.258
Frank Copula	0.592	0.051	-342.727
A-M-H Copula	1.450	0.053	-339.622

Thus, the joint Copula function model for main and tributary floods can be described as follow,

$$C_{Clayton}(u,v) = \left(u^{-0.377} + v^{-0.377} - 1\right)^{-1/0.377} \tag{11}$$

According to the calculation results above, the joint distribution probability of main and tributary floods can be plotted as Figure 3,

Figure 3 joint distribution probability of main and tributary floods

4.2 Analysis of joint characteristics of main and tributary floods

As shown in Figure 4, with a given return period, there are numerous combinations of main and tributary floods. Regardless of *OR* recurrence period and *AND* recurrence period, the recurrence period contours are basically symmetrically distributed with the 45 ° line. This indicates that the main and tributary floods have the same effect on the flood control design of the sluice, however, in actual projects, it is often impossible for the main and tributary floods to have the same effect on the flood control design of the water conservancy project at the tributary inflow. Figure 4 shows the correlation between the main and tributary floods to a certain extent, but fails to show the impact of the main and tributary floods on the flood control design of the project.

Figure4 *p*-level curves of *AND* and *OR* return period

Figure 5a shows the contours calculated by using the Flood Control RP, it's obvious to note that the contour lines under different design recurrence periods tend to be perpendicular to the X coordinate axis, and the greater the recurrence period, the closer the contour lines are to the vertical coordinate axis. This suggests that when the design recurrence period is larger, the influence of the main flood on the flood control design of the sluice is greater. Figure 5b describes the distribution of the main and tributary flood combinations corresponding to the *OR*, *AND* and Flood Control three different design recurrence periods at the recurrence level is 100 years. Different with *OR* and *AND* return periods, each flood combination on the contour line of the Flood

Control RP can obtain an identical design value *z* after the flood adjustment calculation, i.e, the contour line of the Flood Control RP is flood control level contour, *OR* and *AND* return periods are return periods contours. At the same time, Flood Control RP contour is between *OR* and *AND* return periods contours, this indicates that using the Flood Control RP for flood control design calculation can avoid the situations that using the *AND* recurrence period to calculate that the flood control design water level is too small; while using the *OR* recurrence period to calculate the flood control level is too large.

Figure5 a. *p*-level curves of *Flood Control* RP, b. Comparison of three different recurrence periods

4.3 Uncertainty analysis of main and tributary flood combination

According to Serinaldif (2013), the *OR* return period is suggested to be used in multivariate hydrological uncertainty analysis. The actual sample sequence length in this study is 58, thus, 20-year and 50-year *OR* recurrence period are selected as the research object. The joint distribution model established based on the measured data is the whole, and the sample size is set to n = 58 (which is the same as the length of the actual measured sample sequence), 100 and 200 to investigate the effect of the sequence length on the joint design flood combinations.

Before establishing the joint distribution model, the parameter estimation must be carried out. Essentially speaking, the uncertainty of the joint distribution is caused by the parameter uncertainty. The uncertainty analysis of parameters is a mathematical analysis based on statistics, which requires large number of random sampling of parameters. Table3 shows the interval distribution of joint distribution parameters under 95% confidence conditions under different sample sizes based on Monte Carlo simulation. It is noted that with the sample size increase, the parameter amplitude decrease.

Table3 95% confidence interval for joint distribution parameters of different sample sizes

Sample size n	Joint distribution parameter θ	Parameter amplitude
58	(0.390，0.423)	8.243%

100	(0.375 , 0.399)	6.488%
200	(0.383 , 0.401)	4.513%

Figure 6 shows the design contours of the *OR* return period calculated from the measured data and the confidence intervals under different sample sizes. It is noted that under the conditions of the same design return period, the binary confidence interval of the joint design value decreases as the sample size increases. Meanwhile under the same sample size, the binary confidence interval of the joint design value increases as the level of recurrence increases. It is noted that the largest confidence interval area of the joint design value is under the condition that the sample size is n = 58 with the *OR* recurrence period is 50 years, and the confidence interval at the 95% confidence level has covered the contour of the *OR* recurrence period of 10-100 years. At the meanwhile, under the condition that the sample size is n = 200 with the *OR* recurrence period is 20 years, the confidence interval area is smallest which only covered contour of the *OR* recurrence period of 10-20 years. This indicates that when the sample size n is smaller and the design recurrence period is larger, the uncertainty of the joint design value is also greater.

Figure6 Binary confidence interval graph of joint design values

The four uncertainty evaluation indexes were applied to characterize the uncertainty of flood control design under multiple floods, the result is listed in the Table4. It can be concluded from Table4 that when the design recurrence period is given, the four index values decrease with the increase of sample size n, and the decrease is about 20%-50%. When the sample size n is fixed, the four index values increase with the increase of the recurrence period, and the increase is about 20% - 25%. In general, the uncertainty of the joint design combinations under the effect of multiple floods decreases with the increase of sample size n, but increases with the increase of the design return period.

Table4 Calculation Results of Uncertainty Index of Main and Tributary Flood Combination

T_{OR}/	n	D_X/(m^3/s)	D_Y/(m^3/s)	d/(m^3/s)	Confidence interval area/(10^7×m^3/s·m^3/s)		
					50%	75%	95%

year							
20	58	2292.088	1514.948	114.025	1.880	3.722	9.447
	100	1853.864	1094.652	86.538	1.058	2.111	4.928
	200	1317.647	864.390	63.038	0.550	1.117	2.470
50	58	2914.282	2004.538	140.806	3.115	6.658	15.034
	100	2318.090	1605.967	118.578	1.890	3.755	9.146
	200	1764.757	1076.690	82.917	1.022	2.128	4.779

4.4 Uncertainty analysis of flood control design

Take the 20-year return period of design as an example, the results of uncertainty analysis of flood control design are shown in the table5 and Figure7. It is noted from the Figure7 that the flood control design water levels calculated by the *OR* return period are larger than that of Flood Control RP. As shown in Table5, under different sample sizes, the 95% confidence interval and standard deviation of the design value of the 20-year flood control level calculated by the Flood Control RP are less than the *OR* return period. Take the sample size n = 58 as an example, compared with the *OR* return period, the interval length of the Flood Control RP is 14.1% smaller, and the standard deviation is 14.4% smaller, this indicates calculated by the Flood Control RP can reduce the uncertainty of the flood control design water level. At the same time, when n is less than 100, the interval length of both two design standards exceed 60mm, and the standard deviations are greater than 0.5.

Table5 Estimation of flood control level of sluice under different criteria of recurrence period

Recurrence level/year	Return period	*n*	*Z*/(calculated from measured data, m)	*Z*/(expected design value, m)	95% Confidence interval	Interval length/(mm)	Standard deviation
20	*OR*	58	42.33	42.41	(42.36，42.46)	97	0.780
		100		42.44	(42.40，42.48)	76	0.609
		200		42.50	(42.44，42.50)	53	0.429
	FC	58	41.62	42.47	(41.43，41.51)	85	0.682
		100		42.49	(42.45，42.52)	64	0.515
		200		42.53	(42.51，42.56)	44	0.355
50	*OR*	58	43.54	43.51	(43.45，43.57)	116	0.933
		100		43.53	(43.48，43.58)	95	0.766
		200		43.61	(43.57，43.64)	70	0.562
	FC	58	42.71	42.64	(42.59，42.69)	105	0.847
		100		42.66	(42.61，42.70)	83	0.665
		200		42.69	(42.66，42.72)	61	0.493

Figure7 Flood control level box diagram of sluices with different sample capacity under flood control standard a) T=20a, b) T=50a.

5.Conclusion

The calculation of flood control design water level is an extremely important indicators to the hydraulic engineering design and construction. So far as we know, for a single flood condition, the design flood is generally obtained by using the same frequency or the same magnification of the peak and volume, or directly using the peak discharge as the design flood to obtain the design water level. Different from the situation of a single flood, flood control design under the condition of multiple floods is more complicated, the traditional single flood design calculation method is no longer applicable. Base on the Copula function, a new approach to calculate the flood control design water level is proposed, and the uncertainty of the flood combinations and the water level calculated by using different return periods are analyzed.

It is recommended that the Clayton Copula is the most appropriate function to model the joint distribution with the PE3 as the best-fit marginal distribution for main and tributary floods.

Based on the main and tributary floods joint Copula distribution, the OR, AND return periods and the proposed Flood Control RP are investigated. The result indicates that the traditional OR and AND return period cannot describe the different role of main and tributary floods in flood control design, while the Flood Control RP suggests that the main flood plays a more important role than the tributary floods in flood control design.

The result of flood combination uncertainty analysis indicates that the uncertainty of the joint design combinations under the effect of multiple floods decreases with the increase of sample size n, but increases with the increase of the design return period. It is noted that the 95% confidence interval and standard deviation of the design value of flood control design water level calculated by Flood Control RP is smaller than that of OR RP, this suggests that the Flood Control RP can reduce the uncertainty of flood control design water level in this case compared with the traditional OR return period.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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