Reply to Referee #1

This study describes a modeling framework to account for the role of reservoirs in flood frequency analysis. While I think that the topic is generally of interest to the readership of this journal, I have a number of comments that should be addressed before considering it for publication.

Response:

We are truly grateful for your positive comments and helpful suggestions. All your comments have been carefully addressed in the revised manuscript. Please see our point-by-point responses to your comments below.

-The manuscript needs to be proofread more carefully as there are several typos and unclear sentences. I will try point out some of these issues in the comments below, but this is not a complete list.

Response:

Thanks for your advice. We have carefully proofread the manuscript to correct all issues about typos and unclear expressions.

- Line 26: what "previous study"?

Response:

This is corrected as "López and Francés (2013)" in the revised manuscript.

- Lines 46-49: which of the two references is the quote from?

Response:

This quote is summarized by Wyżga et al. (2016). In the revision, this sentence has been changed as follows:

River floods are generated by various complex nonlinear processes involving physical factors including "hydrological pre-conditions (e.g. soil saturation, snow cover), meteorological conditions (e.g. amount, intensity, and spatial and temporal distribution of rainfall), runoff generation processes as well as river routing (e.g. superposition of flood waves in the main river and its tributaries)" (Wyżga et al., 2016).

- Line 49: "nature extreme flow" is unclear.

Response:

We have changed this sentence in the revised manuscript as follows:

In the absence of reservoirs, downstream flood extremes in most rain-dominated basins are mainly related to the corresponding extreme rainfall over the drainage area.…

- Line 46: "this method makes it suitable"

Response:

We can't find this sentence on Line 46. It may be on Line 75. In the revision, this sentence has been rephrased as follows:

The continuous simulation method can explicitly account for the reservoir effects on flood in a hypothetical basin. However, it is difficult to apply this approach to the most real cases (Volpi et al., 2018). The simplifying assumptions are just satisfied in a few of basins with single small reservoir. Even if some basins satisfy the simplifying assumptions, the detailed data and information required in this approach are probably unavailable.

- Line 77: "the first approach". Also, please add a reference to support the statement.

Response:

Corrected. In the revision, we have changed the statement for clarity as follows:

The continuous simulation method can explicitly account for the reservoir effects on flood in a hypothetical basin. However, it is difficult to apply this approach to the most real cases (Volpi et al., 2018). The simplifying assumptions are just satisfied in a few of basins with single small reservoir. Even if some basins satisfy the simplifying assumptions, the detailed data and information required in this approach are probably unavailable.

- Lines 95-96: unclear why you can't get the uncertainties in the estimates. Please clarify.

Response:

Thank you for pointing this out. We realize our statement is imprecise. This statement has been rephrased in the revised manuscript.

For model parameters, the ML can only get one estimate through maximization of the likelihood function, while the Bayesian inference can get multiple estimates, forming a posterior distribution of model parameters. Thus, the ML is inconvenient to describe the uncertainty of flood estimates associated with the model parameter uncertainty.

- Line 98: "all their cases"

Corrected.

- Line 104: "for the expression of the distribution"

Response:

Corrected**.**

- Line 106: "in the expression"

Response:

Corrected.

- Given that you use a GEV but leave the shape parameter constant (and this is fine), please add more 2-parameter distributions (e.g., lognormal, gamma, Weibull, Gumbel) which have only two parameters that you can make vary as a function of your covariates.

Response:

Thank you for this suggestion. In the revision, we have added the four 2-parameter distributions (i.e., lognormal, gamma, Weibull, Gumbel). The results are summarized in Table 7 (newly-added). The results indicate that for the AK and HZ station, the nonstationary WEI model with RRCI has a best performance, while for the HJG station, the nonstationary GA model with RRCI is the best model. In the revision, we have added Table 2 (newly-added) to summarize the used distributions. And the Table 6 and Table 7 are deleted. Detailed analyses of all new results will be included in the revised text. In the revised manuscript, all changes to Tables and Figures are listed as follows:

< Table 1> (revised)

<Table 2> (newly-added)

<Table 3> (Table 2 in the original manuscript; revised)

<Table 5> (Table 4 in the original manuscript; revised)

<Table 6> (Table 5 in the original manuscript; revised)

< Table 7> (newly-added)

< Table 8> (revised)

<Table 5 in the original manuscript> (deleted)

<Table 6 in the original manuscript> (deleted)

<Figure 1> (revised)

<Figure 5> (revised)

<Figure 6> (revised)

<Figure 7> (revised)

<Figure 8> (revised)

<Figure 9 in the original manuscript > (deleted)

- Line 132: "To analyze"

Response:

Corrected.

- Line 139: "The Eq. (1)"

Response:

Corrected.

- If I get this right, you are assuming that the sediment trapping capability of the reservoir is negligible. However, over time the amount of storage decreases. To account for the role of sediment in reducing the reservoir capacity over time, I highly recommend the use of the Brune curve to account for it. If not Brune curve, please account for it in some fashion.

Response:

Thank you for this good and insightful suggestion. To address your comment, RI is redefined to incorporate the impact of sediment on reducing the reservoir capacity over time in discussions. In the revision, RI is defined as

$$RI = \sum_{i=1}^{N} \left(\frac{A_i}{A_T}\right) \bullet \left(\frac{(1 - r_i^{Acc}) \bullet C_i}{R_m}\right) \quad (1)$$

where r_i^{Acc} is the loss rate (%) of reservoir capacity in the i-th reservoir, due to the sediment deposition. The results indicate the loss of the reservoir capacity have an effect but not too big in this study (Figure S2). This is because so far, main reservoirs (i.e., Dangjiangkou and Ankang reservoirs) have a small loss rate no more than 15% (Figure S1). The estimation of r_i^{Acc} has been presented in Supplementary Information (Please see Appendix A).

<Table S1> (newly-added)

<Figure S1> (newly-added)

<Figure S2> (newly-added)

Equation 1 is revised.

Equation S1 is newly-added.

Equation S2 is newly-added.

- Line 157: “the greater the MRI impact”

Response:

Corrected.

- Line 158: what does “inflexible” mean in this context?

Response:

We realize that the word “inflexible” may be inappropriate. Here, what we want to express is that the reservoir scheduling will have more constraints from the MRI. For example, when a large volume MRI occurs and its timing is near the end of flood season, the reservoir will probably face a large peak of inflow and a insufficient residual capacity due to reservoir impounding. The above explaination will been added in the revised manuscript.

- Line 161: “where”

Response:

Corrected.

- In terms of predictors, the spatial distribution of rainfall is not really captured. I can think of situations in which the same basin-averaged rainfall will have very different effects if most of the rainfall occurs far or close to the outlet. How is this addressed here?

Response:

Thank you for your comments. To capture the spatial distribution of rainfall, the distance (L) between the station with the maximum rainfall and the outlet have been considered. However, the results in Figure 5 (revised) show that for HZ station with the drainage area of 142056 km^2, there is a weak positive linear correlation (Pearson’s r=0.24) between L and AMDF, while for the AK station with the drainage area of 38600 km^2 and the HJG station 90491 km^2, the linear correlation between L and AMDF is not significant. In the revised manuscript, this variable is considered as candidate to capture the spatial distribution of rainfall, but this variable is not selected for the calculation of RRCI, in consideration of both the non-significance correlation with floods of the study stations and the very complex fitting of 5-dimension copula.

- Line 185: “marginals”

Response:

Corrected.

- Line 204: "extensively concerned" is unclear.

Response:

- Line 208: what does "obeys nonstationary distribution" mean?

Response:

We have revised this statement as follows:

Suppose that flood variable Y_t obeys distribution $f_{Y_t}(y_t|\boldsymbol{\eta}_t)$ with the covariate-dependent distribution parameters $\boldsymbol{\eta}_t$.

- What about model selection based on the SBC index? Would you get a more parsimonious model?

Response:

Thank you for your suggestion. In the revised manuscript, we have added the SBC index. And a more parsimonious model is selected based on the SBC criterion. After adding four 2-parameter distributions (i.e., lognormal, gamma, Weibull, Gumbel), the detailed results have been summarized in Table 7 (newly-added).

- Line 254: I don't think this statement is correct, given that you would be able to say whether a more complex model should be selected over a more complex one, not if the fit is good or bad.

Response:

Thank you. This statement has been deleted. In the revised manuscript, the chi-square test has been replaced by the SBC criterion.

- Line 266: ", and was completed"

Response:

Corrected.

- Line 281: what is the definition of "timing"?

Response:

The timing is defined as the time on which day of the year the annual maximum daily flood occurred. In the revision, the definition of "timing" will be added.

- Line 303: what does "special" mean?

Response:

In the revision, this sentence has been deleted.

- Line 314: "was calculated"

Response:

Corrected.

- In fitting the copulas, the marginals were treating as stationary. Is this really the case? Please test for the presence of nonstationarities in the marginals of the predictors. If nonstationary, please account for it.

Response:

Thanks. In the revision, the change-points of the variables are tested by the Pettitt test, and then, if any, the marginal with the change-point will be addressed by the estimation method (Xiong et al., 2015). The results in Table S2 show that there are the significant change-points in the mean intensity (*I*) of the AK and HJG stations and in the volume (*V*) of the HJG station. Results in Table 5 indicate that the consideration of the nonstationarity in these marginals makes little difference.

< Table S2> (newly-added)

- The role of the Mann-Kendall and Pettitt tests is unclear to me. First of all, the results are discussed at a very basic and superficial level. Also, if the response variable tends to change with time but because the predictors you have selected change over time as well, then whether Y is stationary or not is not very important; however, whether the relationship between predictors and predictand doesn't change over time becomes more relevant. Please fix this part.

Response:

Thanks. Here, the Mann-Kendall and Pettitt tests are indeed non-essential. We have deleted the Mann-Kendall and Pettitt tests in the revised manuscript.

It is hard to demonstrate whether the relationship between predictors and predictand doesn't change over time in this study. But this issue can be covered, because under the Bayesian framework, the uncertainty of the change of this relationship will be reflected in the posteriori distribution of model parameters.

- Lines 362-364: Please apply a correction to account for the fact you are performing multiple hypothesis testing

Response:

The correction has been made.

- Line 374: “explains”

Response:

Corrected.

- Line 391: “for every certain multivariate MRI” is unclear.

Response:

Revised.

- Line 402: “It is of interest”

Response:

Corrected.

- Line 404: “the remaining capacity of the reservoir”

Response:

Corrected.

- Line 409: “due to correspond to” is unclear

Response:

Revised.

- Line 423: “related to the construction”

Response:

Corrected.

- Line 427: “is weak”; “The comparison”

Response:

Corrected.

- Line 428: “indicates”

Response:

Corrected.

- Line 429: “in most cases”

Response:

Corrected.

- Line 435: “100-year”

Response:

Corrected.

- Line 649: “thick blue” what?

Response:

We have changed this in the revised manuscript as follows:

…the thick blue lines…

- Line 651: “The right panels are”

Response:

Corrected.

Tables (revised and newly-added)

Table 1. Seven scenarios for the formulas of the two distribution parameters (i.e., μ_t σ_t).

Scenario codes	The formula of distribution parameters	
	$g_1(\mu_t)$	$g_2(\sigma_t)$
S0	μ_0	σ_0
S11	$\mu_0+\mu_1$RI	σ_0
S12	μ_0	$\sigma_0+\sigma_1$RI
S13	$\mu_0+\mu_1$RI	$\sigma_0+\sigma_1$RI
S21	$\mu_0+\mu_1$RRCI	σ_0
S22	μ_0	$\sigma_0+\sigma_1$RRCI
S23	$\mu_0+\mu_1$RRCI	$\sigma_0+\sigma_1$RRCI

Table 2. Summary of the probability density functions and the used link functions for nonstationary frequency modeling of the flood series.

Distributions	Probability density functions	Link functions
Gamma (GA)	$f_Y\left(y\middle|\mu_t,\sigma_t\right)=\frac{(y)^{1/\sigma_t^2-1}}{\Gamma\left(1/\sigma_t^2\right)\left(\mu\sigma_t^2\right)^{1/\sigma_t^2}}\exp\left(-\frac{y}{\mu_t\sigma_t^2}\right)$ $y>0,\mu_t>0,\sigma_t>0$	$g_1(\mu_t)=\ln(\mu_t)$ $g_2(\sigma_t)=\ln(\sigma_t)$
Weibull (WEI)	$f_Y\left(y\middle|\mu_t,\sigma_t\right)=\left(\frac{\sigma_t}{\mu_t}\right)\left(\frac{y}{\mu_t}\right)^{\sigma_t-1}\exp\left(-\left(\frac{y}{\mu_t}\right)^{\sigma_t}\right)$ $y>0,\mu_t>0,\sigma_t>0$	$g_1(\mu_t)=\ln(\mu_t)$ $g_2(\sigma_t)=\ln(\sigma_t)$
Lognormal (LOGNO)	$f_Y\left(y\middle|\mu_t,\sigma_t\right)=\frac{1}{y\sigma_t\sqrt{2\pi}}\exp\left\{-\frac{\left[\log(y)-\mu_t\right]^2}{2\sigma_t^2}\right\}$ $y>0,-\infty<\mu_t<\infty,\sigma_t>0$	$g_1(\mu_t)=\ln(\mu_t)$ $g_2(\sigma_t)=\ln(\sigma_t)$
Gumbel (GU)	$f_Y\left(y\middle|\mu_t,\sigma_t\right)=\frac{1}{\sigma_t}\exp\left\{\left(\frac{y-\mu_t}{\sigma_t}\right)-\exp\left(\frac{y-\mu_t}{\sigma_t}\right)\right\}$ $-\infty<y<\infty,-\infty<\mu_t<\infty,\sigma_t>0$	$g_1(\mu_t)=\mu_t$ $g_2(\sigma_t)=\ln(\sigma_t)$
Generalized Extremes Value (GEV)	$f_Y\left(y\middle|\mu_t,\sigma_t,\xi\right)=\frac{1}{\sigma_t}\left[1+\xi\left(\frac{y-\mu_t}{\sigma_t}\right)\right]^{-1/\xi-1}\exp\left\{-\left[1+\xi\left(\frac{y-\mu_t}{\sigma_t}\right)\right]^{-1/\xi}\right\}$ $y>\mu_t-\sigma_t/\xi,-\infty<\mu_t<\infty,\sigma_t>0,-\infty<\xi<\infty$	$g_1(\mu_t)=\mu_t$ $g_2(\sigma_t)=\ln(\sigma_t)$

Table 3. The information of the reservoirs in the Hanjiang River basin.

Reservoirs	Longitude	Latitude	Area (km^2)	Year	Capacity (10^9 m^3)
Shiquan	108.05	33.04	23400	1974	0.566
Ankang	108.83	32.54	35700	1992	3.21
Huanglongtan	110.53	32.68	10688	1978	1.17
Dangjiangkou	111.51	32.54	95220	1967	34
Yahekou	112.49	33.38	3030	1960	1.32

Table 5. Correlation coefficients between the RRCI and the AMDF.

Subset of rainfall variables	AK			HJG			HZ		
	Pearson	Kendall	Spearman	Pearson	Kendall	Spearman	Pearson	Kendall	Spearman
-*	-0.37	-0.18	-0.28	-0.55	-0.37	-0.54	-0.53	-0.38	-0.55
M	-0.27	-0.27	-0.37	-0.67	-0.53	-0.74	-0.45	-0.37	-0.51
I	-0.26	-0.25	-0.34	**-0.74**	-0.57	-0.79	-0.54	-0.41	-0.56
V	-0.32	-0.28	-0.39	-0.63	-0.49	-0.69	-0.57	-0.48	-0.65
T	-0.11	-0.17	-0.24	-0.68	-0.55	-0.73	-0.48	-0.40	-0.57
M, *I*	-0.36	-0.28	-0.38	-0.70	-0.56	-0.77	-0.56	-0.43	-0.58
M, *V*	-0.42	-0.29	-0.40	-0.64	-0.50	-0.71	-0.56	-0.45	-0.60
M, *T*	-0.37	-0.26	-0.36	-0.69	-0.57	-0.77	-0.64	-0.46	-0.63
I, *V*	-0.46	-0.31	-0.42	-0.71	-0.54	-0.76	-0.65	-0.50	-0.67
I, *T*	-0.34	-0.22	-0.31	-0.73	**-0.60**	**-0.80**	-0.68	-0.50	-0.66
V, *T*	-0.43	-0.28	-0.39	-0.68	-0.55	-0.75	-0.69	-0.52	-0.71
M, *I*, *V*	-0.49	-0.31	-0.42	-0.65	-0.53	-0.74	-0.63	-0.47	-0.63
M, *I*, *T*	-0.41	-0.27	-0.37	-0.68	-0.57	-0.78	-0.67	-0.49	-0.66
M, *V*, *T*	-0.50	-0.29	-0.40	-0.65	-0.56	-0.76	-0.67	-0.49	-0.67
I, *V*, *T*	-0.51	-0.31	-0.41	-0.67	-0.58	-0.78	**-0.71**	**-0.53**	**-0.70**
M, *I*, *V*, *T*	**-0.53**	**-0.31**	**-0.42**	-0.65	-0.57	-0.77	-0.69	-0.52	-0.69

*The values in the first row are the correlation coefficients between RI and flood seires

Table 6. Results of copula models.

Stations	Scheduling-related variables	Pairs	Copula type	Parameters θ_c	Kendall's tau	Goodness-of-fit test based on the empirical copula	
						CvM*	p-value
AK	M, I, V, T	14	Clayton	0.16	0.08	0.169	0.86
		13	Clayton	1.28	0.39		
		12	Clayton	1.01	0.33		
		24|1	Frank	1.21	0.17		
		23|1	Frank	-2.24	-0.24		
		34|12	Clayton	0.96	0.11		
HJG	I, T	24	Clayton	1.37	0.41	0.473	0.425
HZ	I, V, T	24	Gumbel	1.12	0.11	0.181	0.82
		23	Clayton	1.31	0.40		
		34|2	Clayton	0.49	0.2		

* CvM is the statistic of the Cramer-von Mises test; if the p-value of the C-vine copula model is less than the significance level of 0.05, the model is considered to be not consistent with the empirical copula.

Table 7. Summary of results of the nonstationary distribution models.

Stations	Covariates	Distributions	The optimal formulas* of distribution parameters				AIC	SBC
			Selected models	μ_t	σ_t	ξ_0		
AK	RI	GA	WEI_S23	exp(9.24-2.64RI)	exp(-0.769+2.9RI)	-	1177.2	1185.5
	RI	WEI		exp(9.36-2.83RI)	exp(0.882-3.18RI)	-	1176.9	1185.3
	RI	LOGNO		exp(9.14-3.86RI)	exp(-0.716+3.28RI)	-	1180.4	1188.8
	RI	GU		11875-13093RI	exp(8.5)	-	1199.6	1205.9
	RI	GEV		7685-15252RI	exp(8.3)	-0.043	1182.3	1190.6
	RRCI	GA		exp(9.28-1.11RRCI)	exp(-0.825+0.689RRCI)	-	1165.3	1173.7
	RRCI	WEI		exp(9.4-1.17RRCI)	exp(0.982-0.884RRCI)	-	1163.8	**1172.2**
	RRCI	LOGNO		exp(9.19-1.33RRCI)	exp(-0.749+0.677RRCI)	-	1168.0	1176.4
	RRCI	GU		12555-7535RRCI	exp(8.4)	-	1188.0	1194.2
	RRCI	GEV		8460-6722RRCI	exp(8.2)	-0.096	1172.1	1180.5
HJG	RI	GA	GA_S21	exp(9.7-1.62RI)	exp(-0.25)	-	1139.9	1146.0
	RI	WEI		exp(9.75-1.56RI)	exp(0.27)	-	1141.4	1147.5
	RI	LOGNO		exp(9.47-1.8RI)	exp(-0.17)	-	1140.9	1147.1
	RI	GU		17955-14399RI	exp(8.8)	-	1189.5	1195.7
	RI	GEV		6976-5930RI	exp(8.79-1.49RI)	0.43	1149.9	1160.2
	RRCI	GA		exp(9.99-1.99RRCI)	exp(-0.45)	-	1112.5	**1118.6**
	RRCI	WEI		exp(10.1-1.97RRCI)	exp(0.53)	-	1113.2	1119.4
	RRCI	LOGNO		exp(9.75-1.94RRCI)	exp(-0.38)	-	1113.9	1120.1
	RRCI	GU		23067-20871RRCI	exp(9.2-1.7RRCI)	-	1121.3	1129.6
	RRCI	GEV		12113-10683RRCI	exp(9.2-2.01RRCI)	0.051	1112.5	1122.8
HZ	RI	GA	WEI_S21	exp(9.85-2.87RI)	exp(-0.42)	-	1198.3	1204.9
	RI	WEI		exp(9.94-2.79RI)	exp(0.49)	-	1198.6	1204.9
	RI	LOGNO		exp(9.63-2.93RI)	exp(-0.33)	-	1201.1	1207.4
	RI	GU		18661-23706RI	exp(8.8)	-	1237.5	1243.7
	RI	GEV		9605-13545RI	exp(9.03-2.56RI)	0.099	1207.8	1218.3
	RRCI	GA		exp(9.85-1.52RRCI)	exp(-0.61)	-	1173.1	1179.4
	RRCI	WEI		exp(9.92-1.42RRCI)	exp(0.73)	-	1171.2	**1177.5**
	RRCI	LOGNO		exp(9.72-1.55RRCI)	exp(-0.51)	-	1178.7	1185.0
	RRCI	GU		19214-14344RRCI	exp(8.86-0.881RRCI)	-	1189.7	1198.1
	RRCI	GEV		12502-9911RRCI	exp(8.96-1.37RRCI)	-0.068	1176.0	1186.4

*The model parameters in the optimal formulas are the posterior mean from Bayesian inference.

Table 8. The top-5 floods and the corresponding RRCI, $P_{MRI}^{\vee}$ and scheduling-related rainfall variables after the construction (1967) of Danjiangkou reservoir in the HZ station.

Year	AMDF (m^3/s)	Values (Ranking in 1967-2015)					
		RRCI	RI	$P_{MRI}^{\vee}$	I	V	T
1983	25600	0.136 (2)	0.294 (-)	0.435 (2)	20.2 (1)	121.4 (19)	281 (2)
1975	19900	0.247 (7)	0.295 (-)	0.557 (7)	9.6 (18)	163.6 (13)	277 (6)
1974	18200	0.197 (4)	0.296 (-)	0.506 (4)	12.0 (7)	120.4 (20)	278 (4)
2005	16800	0.369 (12)	0.301(-)	0.651 (11)	8.2 (27)	179.7 (10)	278 (4)
1984	16100	0.155 (3)	0.294 (-)	0.461 (3)	9.9 (15)	256.3 (4)	273 (9)

Figures (revised and newly-added)

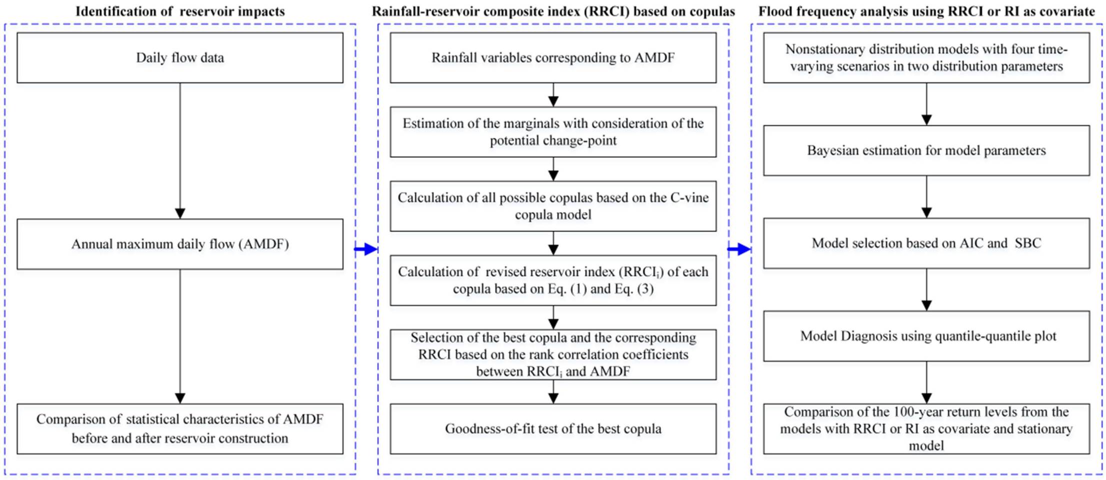

Figure 1. The flowchart of nonstationary covariate-based flood frequency analysis with a rainfall-reservoir composite index (RRCI).

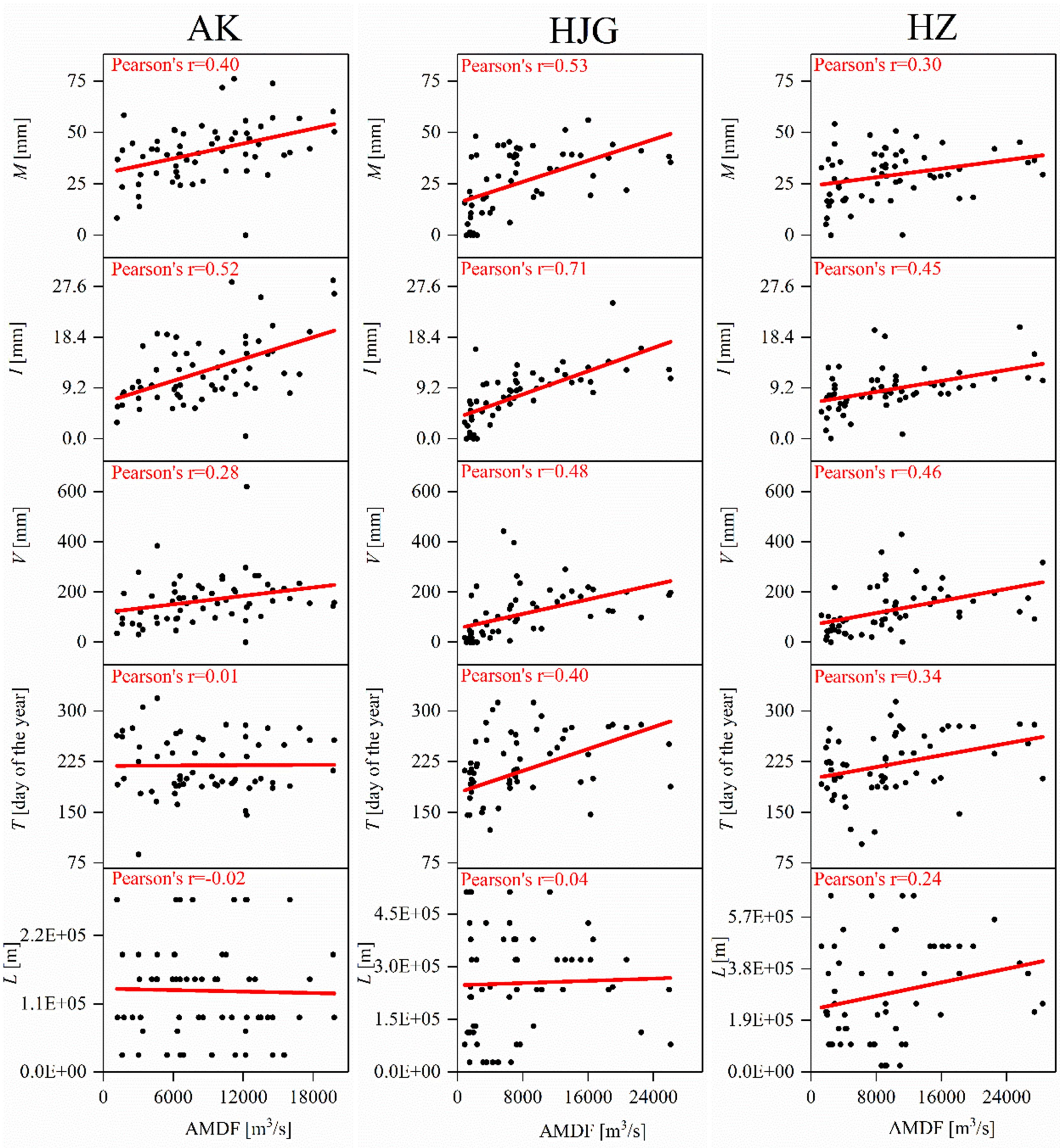

Figure 5. Linear correlation between the variables of multivariate MRI and AMDF.

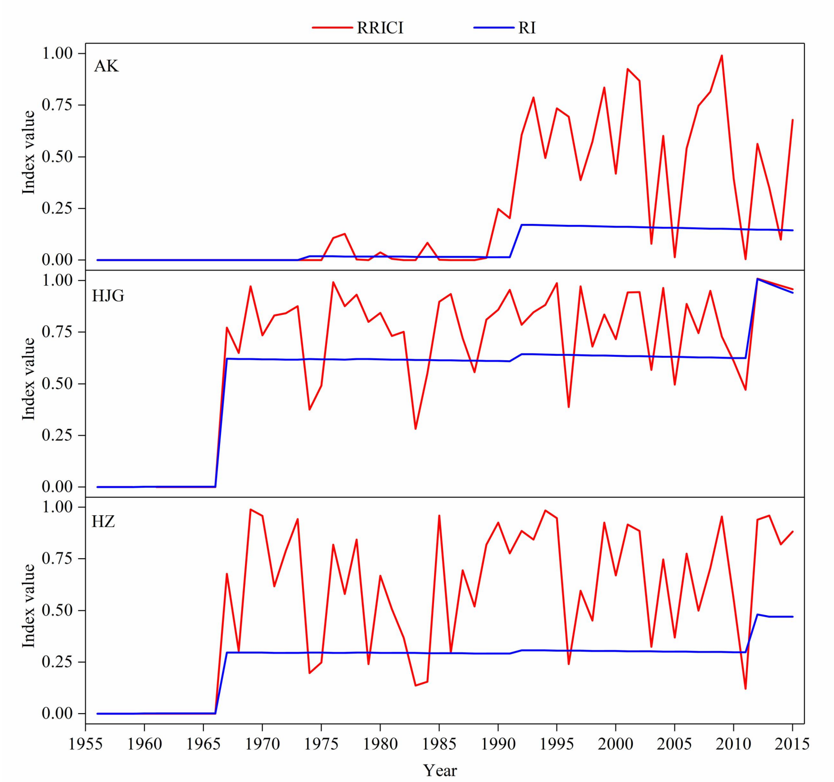

Figure 6. Variation of RI and RRCI.

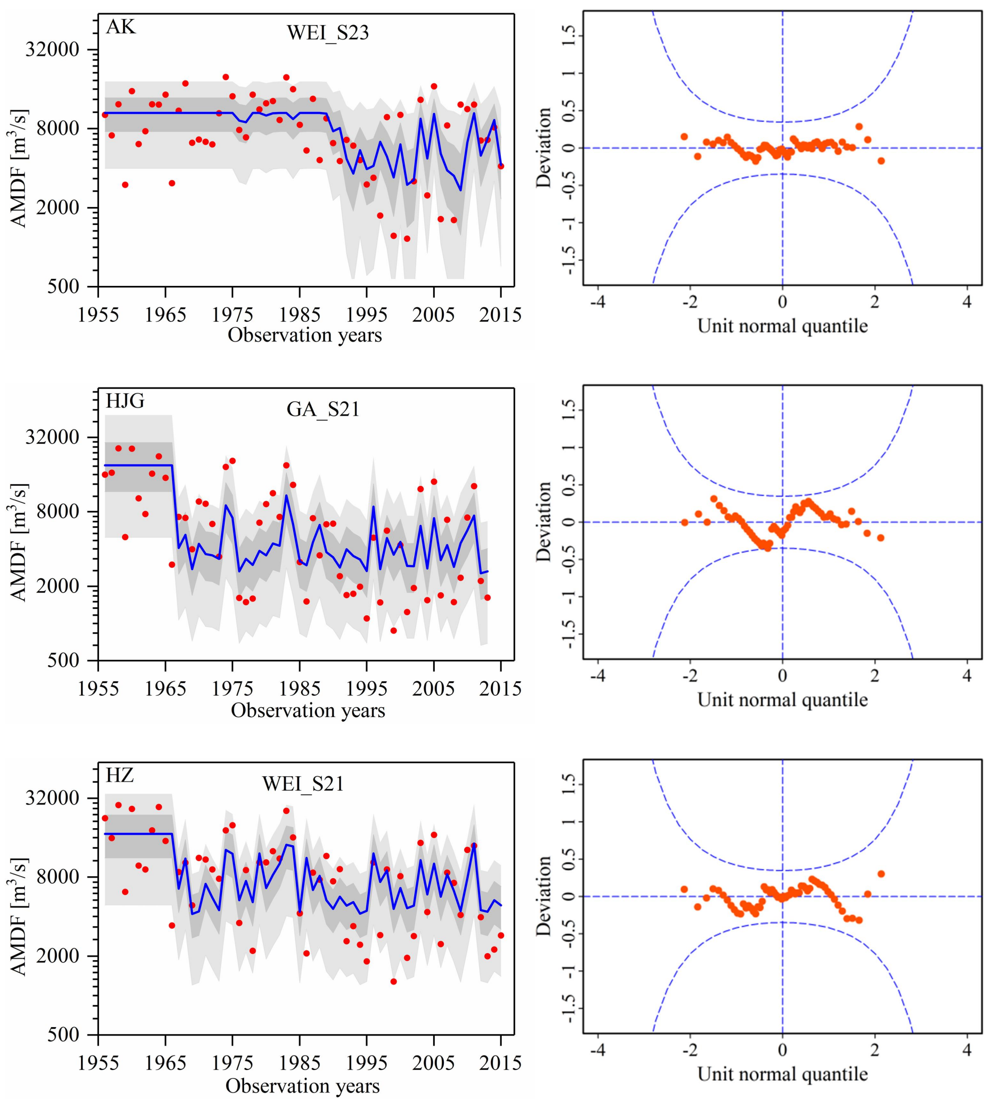

Figure 7. The performance of the best models (WEI_S23 for AK station, GA_S21 for HJG station and WEI_S21 for HZ station). The left panels are the centile curves plots (the 50th centile curves are indicated by the thick blue lines; the light gray-filled areas are between the 5th and 95th centile curves; the dark grey-filled areas are between the 25th and 75th centile curves; the filled red points indicate the observed series). The right panels are the worm plots; a reasonable model should have the plotted points within the 95% confidence intervals (between the two blue dashed curves).

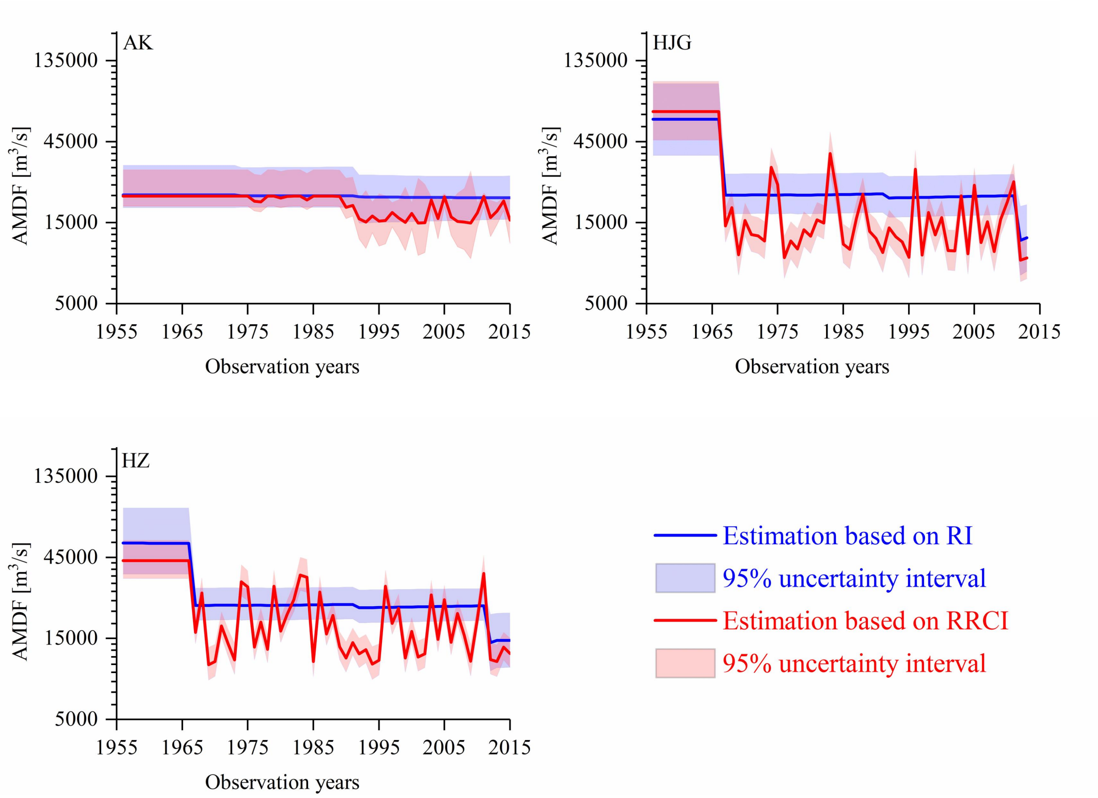

Figure 8. Statistical inference of the 100-year return levels from the models (WEI_S13 and WEI_S23 for AK station, GA_S11 and GA_S21 for HJG station and WEI_S11 and WEI_S21 for HZ station) with the 95% uncertainty interval.

Appendix A: Supplementary Information

The estimation of the loss rate (%) of reservoir capacity

In this study, to estimate the variation of r_i^{Acc} over time, it is assumed that there is the same amount of sediment in each year. Then, r_i^{Acc} is estimated by

$$r_i^{Acc} = \frac{n_i L_i^m}{C_i} = \frac{n_i \bullet w_i^s \bullet Te_i}{\rho C_i} \tag{S2}$$

where n_i is the number of years the i-th reservoir has been used, L_i^m is the mean of annual loss of reservoir capacity (m^3), w_i^s is the mean of annual inflow sediment mass (kg), ρ is the density of the deposited sediment (kg/m^3) and Te_i is the trap efficiency (%). Based on the Brune method (Brune, 1953; Mulu and Dwarakish, 2015), the trap efficiency is estimated with reservoir capacity-inflow ratio as follows

$$Te_i = 1 - \frac{0.5}{\sqrt{C_i/I_i}} \tag{S2}$$

where I_i is the mean of annual inflow volume in the i-th reservoir (m^3/day). The data in the previous literature (Guo, 1995; Hu, 2009; Liu, 2017) are collected to control the estimation errors of L_i^m. Please see Table S1.

Reference:

Hu, A.Y., 2009. Analysis of sedimentation characteristics of Danjiangkou Reservoir. Research in Soil and Water Conservation, 16(5):237-240. (In Chinese)

Brune, G.M., 1953. Trap Efficiency of Reservoirs. Trans. Am. Geophysical Union, 34 (3), 407-418.

Guo, J.M., 1995. Analysis of sedimentation in Ankang Reservoir and its impact on the reservoir operation. Northwest Hydropower, 1995(3):9-12. (In Chinese)

Liu, J.X., 2017. Sedimentation characteristic analysis and desilting scheme optimization of Shiquan Reservoir. Pearl River, 38(1): 56-59. (In Chinese)

Mulu, A., and Dwarakish G. S., 2015. Different Approach for Using Trap Efficiency for Estimation of Reservoir Sedimentation. An Overview, Aquatic Procedia, 4, 847-852.

Table S1. Summary for the calculation of the mean of annual loss of reservoir capacity

Reservoirs	C_i (10^9 m^3)	I_i (10^9 m^3)	w_i^s (10^9 kg)	Te_i (%)	L_i^m (10^9 m^3) From previous studies	L_i^m (10^9 m^3) From Eq.(S2)*
Shiquan	0.566	11.73	12.6	88%	0.006	0.008
Ankang	3.21	19.17	27.1	94%	-	0.018
Huanglongtan	1.17	6.12	8.58	94%	0.007	0.006
Dangjiangkou	34.0	39.48	59.8	97%	0.044	0.042
Yahekou	1.32	1.09	-	98%	0.007	-

* ρ = 1400 kg/m^3 .

Table S2. Results of the change-point detection for the rainfall series.

Variables	AK		HJG		HZ	
	change-point	p-value*	change-point	p-value	change-point	p-value
M	1976	1.037	1989	0.371	1971	1.278
I	1987	**0.031**	1985	**0.009**	1990	0.080
V	2009	0.746	1984	**0.042**	1984	0.769
T	1992	1.180	1984	0.986	1984	1.367

*Less than 0.05 is considered significant.

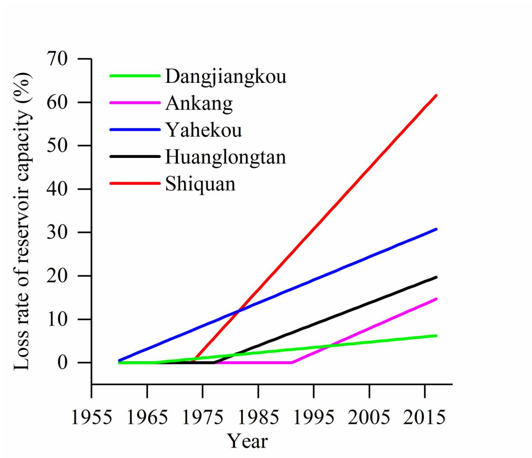

Figure S1. Interannual variation of loss rate of reservior capacitity for each reservoir in the study area.

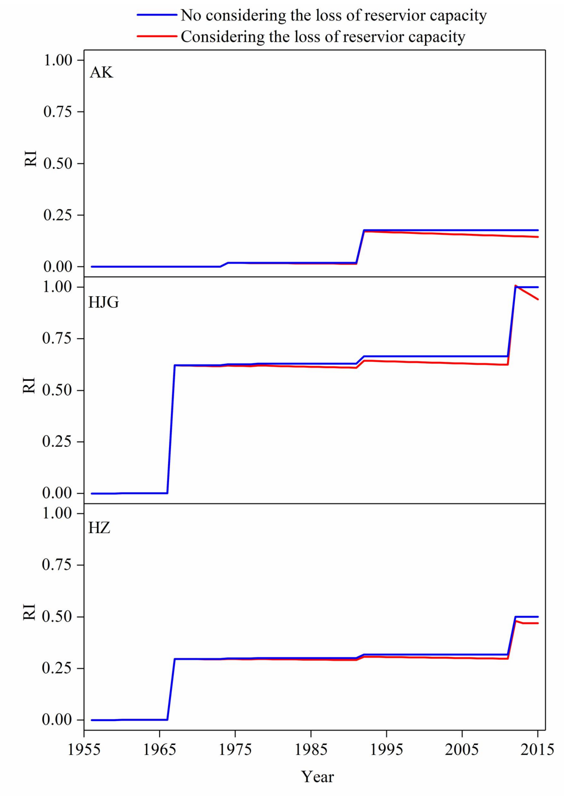

Figure S2. The impact of reservoir capacity loss on RI for AK, HJG and HZ stations.

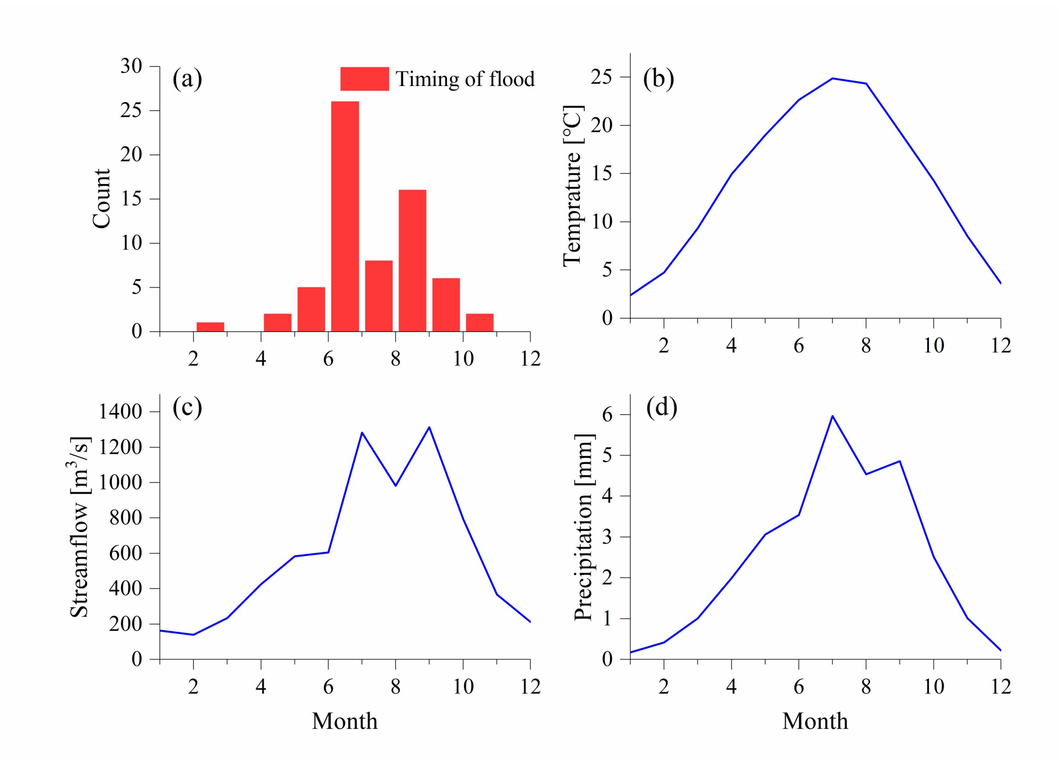

Figure S3 Preliminary analysis of the snowmelt contribution of the catchment upstream the AK station. (a) is the timing of flood; (b) is the monthly average temperature; (c) is the monthly average streamflow; and (d) is the monthly average precipitation.