Supplementary Materials: Risk Assessment and Decision-Making Based on Mean-CVaR-Entropy for Flood Control Operation of Large Scale Reservoirs

1. Extraction Method of Reservoir Capacity Allocation Scheme

To achieve the full potential of flood control in the multi-reservoir group, judicious multi-reservoir joint operation scheme is needed. The effectiveness of multi-reservoir joint operation policy relies on two factors, the form and derivation method of operation rules [1]. For this, a combined simulation-optimization model was developed to extract the operation scheme. The simulation model, namely the form of the operation scheme, was run to determine the objective of the optimization model associated with parameters about the operation scheme. The optimization model was established to find the optimal decision variables, which were the parameters about the operation scheme in the simulation model. And the particle swarm optimization algorithm, namely the derivation method of operation schemes, was selected, owing to its powerful and robust performance and simplicity in combining with a simulation technique [2]. The schematic of the model was shown in Figure S1.

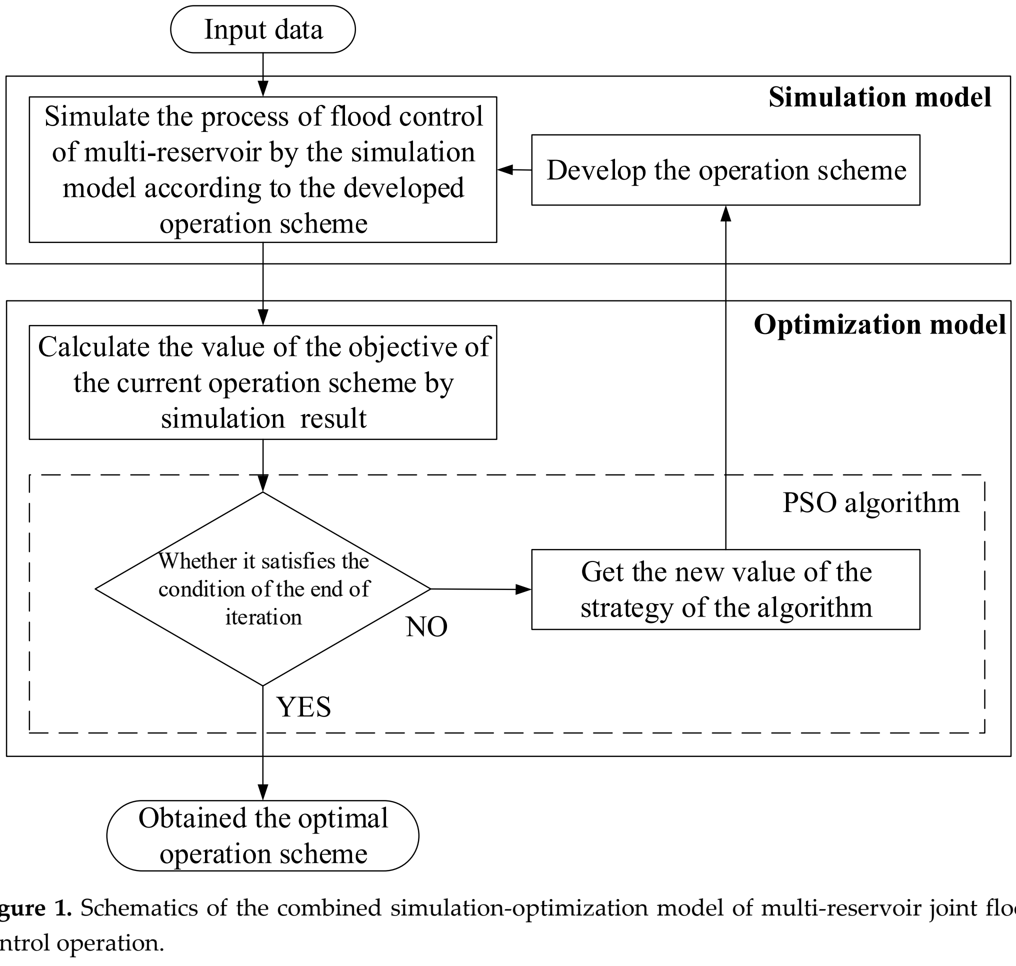

Figure 1. Schematics of the combined simulation-optimization model of multi-reservoir joint flood control operation.

2. Multi-Reservoir Joint Flood Control Operation Scheme

In this study, the 14 large reservoirs on various tributaries of the Yangtze River Basin were selected as a case study. On the basis of the multi-reservoir joint flood control operation framework proposed by Li et al. [3], a series of parameters were used to characterize an quantify the timing and amount of reservoir interception of each reservoir. At the same time, a simulation model was established based on the constraints of water level and discharge flow during the actual reservoir operation, as well as the flow constraints at flood control points. Furthermore, the particle swarm optimization (PSO) algorithm was applied to optimize the parameters according to the specified objectives, and a number of feasible flood control operation schemes are obtained.

The form of the operation scheme was shown in Table S1. Some constraints, shown as follow, were considered and then the simulation model was established.

(1) Water level constraint:

$$Z_{i,t}^{\min} \le Z_{i,t} \le Z_{i,t}^{\max}, \tag{S1}$$

where $Z_{i,t}^{\min}$ and $Z_{i,t}^{\max}$ are the upper and lower water level limits of the i^{th} reservoir at time t, respectively.

(2) Outflow level constraint

$$q_{i,t}^{\min} \le q_{i,t} \le q_{i,t}^{\max}, \tag{S2}$$

where $q_{i,t}^{\min}$ and $q_{i,t}^{\max}$ are the upper and lower release limits of the i^{th} reservoir at time t, respectively.

(3) The safety of flood control point constraint

$$Q_t^P < Q_{\text{safe}}^P, \tag{S3}$$

where Q_t^P and Q_{safe}^P are the real flow and safe flow of flood control point at time t, respectively; P represents the Panzhihua City in Jinsha River, Lizhuang and Zhutuo station in the Chuan River, Shaping section of Chengkun railway in Dadu River, Nanchong city in the Jialing River and Sinan county in Wu River.

Since the area of the downstream of the Yangtze River was of importance, the objective of the optimization model was to minimize the maximal water level of TGR during the operation period, shown as follow:

$$\min F = \min\left\{\max\left\{z_1, z_2 \ldots z_T\right\}\right\}, \tag{S3}$$

where z_i is the water level of TGR at time t; T is the operation period.

The decision variables were the set of parameters x_i defined in Table S1. The range of these variable, shown in Table S2, were determined based on the information of project with the title of "impact of flood control multi-reservoir co-operation in the upper Yangtze River Basin on the Three Gorges Reservoir and its corresponding risk analysis".

Note: On Table S3, $Z_{sx,t}$ is the water level of the TGR at time t; $Q_{sx,t+i}$ is the predicted flow at next i time step of TGR. $Q_{jz,t}$, $Q_{ylj,t}$, $Q_{pbg,t}$, $Q_{tzk,t}$ and $Q_{gpt,t}$ are the instream of Liyuan reservoir, Jinpinyiji reservoir, Pubugou reservoir, Tingzikou reservoir and Goupitan reservoir at time t. Furthermore, the impound flow of cascade reservoir in the middle of Jinsha River and Yalong River was both distributed among the reservoirs at the ratio of the reservoir flood control storage and the operation mode of each reservoir in cascade reservoir Lower reaches of the Jinsha River could refer to Li et al. [3].

Seven typical flood hydrographs, which caused huge disasters in the Yangtze River Basin in the past 100 years, were selected from the perspective of flood magnitude, disaster severity, occurring time and flood composition. Most of the selected typical floods occurred in July or August, in terms of the region distribution, the types of the typical flood, which include the upstream type, downstream type and whole basin type. Most of the typical flood peak types are multi-peak and double-peak. The flood process of the typical flood lasted a long time, which is the characteristics of the floods in the middle and lower reaches of the Yangtze River. However, the single-peak flood with a shorter duration was also chosen. The selected design flood hydrographs were input in the combined simulation-optimization model and seven optimal operation schemes which are suitable for different types of flood, were obtained (Table S3-S9). For example, Scheme 1 and Scheme 7 are suitable for dealing with flood in the whole basin, and Scheme 4 is suitable for dealing with flood types with larger inflow in the interval. Scheme 8 (Table S10) is obtained by synthetically considering seven typical flood processes, and Scheme 9 (Table S11) is the existing joint operation scheme. All feasible schemes (Table S3-S11) are used for risk analysis and decision-making in the next step.

Table S1. The form of the operation scheme of multi-reservoir joint flood control.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water level of TGR（m）	Instream of TGR(m^3/s)	Reservoir Instream (m^3/s)	Impound Flow (m^3/s)	Water Level of TGR（m）	Instream of TGR(m^3/s)	Reservoir Discharge(m^3/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq x_1$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < x_2$	x_3	$Z_{sx,t} < 158$	$Q_{sx,t+3} < x_5$	$Q_{jz,t} + x_6$
			$Q_{jz,t} \geq x_2$	x_4			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq x_7$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < x_8$	x_9	$Z_{sx,t} < 158$	$Q_{sx,t+3} < x_{11}$	$Q_{ylj,t} + x_{12}$
			$Q_{ylj,t} \geq x_8$	x_{10}			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq x_{13}$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq x_{19}$	$Q_{xx,t} + x_{20}$
		$Q_{sx,t+2} < x_{14}$	-	x_{16}			
		$Q_{sx,t+2} < x_{15}$	-	x_{17}			
		$Q_{sx,t+2} \geq x_{15}$	-	x_{18}			
Pubugou	$Z_{sx,t} \geq x_{21}$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < x_{22}$	x_{23}	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq x_{25}$	$Q_{pbg,t} + x_{26}$
			$Q_{pbg,t} \geq x_{22}$	$(Q_{pbg,t} - x_{22})/2 + x_{24}$			
Tingzikou	$Z_{sx,t} \geq x_{27}$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < x_{28}$	x_{29}	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq x_{31}$	$Q_{tzk,t} + x_{32}$
			$Q_{tzk,t} \geq x_{28}$	X_{30}			
Goupitan	$Z_{sx,t} \geq x_{33}$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < x_{34}$	x_{35}	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq x_{37}$	$Q_{gpt,t} + x_{38}$
			$Q_{gpt,t} \geq x_{34}$	x_{36}			

Table S2. The range of the decision variable of the optimization model.

Decision Variable	Range	Decision Variable	Range	Decision Variable	Range	Decision Variable	Range	Decision Variable	Range
X_1	[145–158]	X_9	[1000–2500]	X_{17}	[5000–7000]	X_{25}	[46000–50000]	X_{33}	[145–158]
X_2	[4000–6000]	X_{10}	[2000–3500]	X_{18}	[9000–11000]	X_{26}	[500–2000]	X_{34}	[2000–4000]
X_3	[500–2000]	X_{11}	[46000–50000]	X_{19}	[46000–50000]	X_{27}	[145–158]	X_{35}	[500–1500]
X_4	[2000–4000]	X_{12}	[500–2000]	X_{20}	[2000–4000]	X_{28}	[5000–7000]	X_{36}	[1000–3000]
X_5	[46000–50000]	X_{13}	[145–158]	X_{21}	[145–158]	X_{29}	[2000–3000]	X_{37}	[46000–50000]
X_6	[500–2000]	X_{14}	[50000–70000]	X_{22}	[2000–4000]	X_{30}	[2000–4000]	X_{38}	[500–2000]
X_7	[145–158]	X_{15}	[60000–80000]	X_{23}	[500–1500]	X_{31}	[46000–50000]		
X_8	[3000–5000]	X_{16}	[3000–5000]	X_{24}	[500–2000]	X_{32}	[500–2000]		

Table S3. Multi reservoir joint flood control operation Scheme 1 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR（m）	Instream of TGR(m^3/s)	Reservoir Instream (m^3/s)	Impound Flow (m^3/s)	Water Level of TGR（m）	Instream of TGR(m^3/s)	Reservoir Discharge(m^3/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 146$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 5600$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 50{,}000$	$Q_{jz,t} + 2000$
			$Q_{jz,t} \geq 5600$	2500			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 147$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 4000$	2500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{ylj,t} + 2000$
			$Q_{ylj,t} \geq 4000$	3500			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 146$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}000$	$Q_{xx,t} + 3100$
		$Q_{sx,t+2} < 62{,}800$	-	5000			
		$Q_{sx,t+2} < 75{,}000$	-	7800			
		$Q_{sx,t+2} \geq 75{,}000$	-	9700			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 2000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 46{,}000$	$Q_{pbg,t} + 2000$
			$Q_{pbg,t} \geq 2000$	$(Q_{pbg,t} - 2000)/2 + 500$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 7000$	4000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 48{,}200$	$Q_{tzk,t} + 1300$
			$Q_{tzk,t} \geq 7000$	5000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 3000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 50{,}000$	$Q_{gpt,t} + 500$
			$Q_{gpt,t} \geq 3000$	2300			

Table S4. Multi reservoir joint flood control operation Scheme 2 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Instream (m³/s)	Impound Flow (m³/s)	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 4000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{jz,t} + 2000$
			$Q_{jz,t} \geq 4000$	3700			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 4000$	1100	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}700$	$Q_{ylj,t} + 900$
			$Q_{ylj,t} \geq 4000$	3500			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+2} \geq 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}000$	$Q_{xx,t} + 3600$
		$Q_{sx,t+2} < 70{,}000$	-	5000			
		$Q_{sx,t+2} < 75{,}000$	-	5500			
		$Q_{sx,t+2} \geq 75{,}000$	-	11000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 2000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 46{,}100$	$Q_{pbg,t} + 2000$
			$Q_{pbg,t} \geq 2000$	$(Q_{pbg,t} - 2000)/2 + 500$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 7000$	4000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{tzk,t} + 1100$
			$Q_{tzk,t} \geq 7000$	5000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 3300$	500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{gpt,t} + 500$
			$Q_{gpt,t} \geq 3300$	2500			

Table S5. Multi reservoir joint flood control operation Scheme 3 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Instream (m³/s)	Impound Flow (m³/s)	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 6000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{jz,t} + 2000$
			$Q_{jz,t} \geq 6000$	3500			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 5000$	2500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 50{,}000$	$Q_{ylj,t}+ 2000$
			$Q_{ylj,t} \geq 5000$	3000			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}000$	$Q_{xx,t}+ 2000$
		$Q_{sx,t+2} < 60{,}000$	-	5000			
		$Q_{sx,t+2} < 75{,}000$	-	5500			
		$Q_{sx,t+2} \geq 75{,}000$	-	9000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 2000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 50{,}000$	$Q_{pbg,t}+ 500$
			$Q_{pbg,t} \geq 2000$	$(Q_{pbg,t} - 2000)/2 + 700$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 5000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{tzk,t}+ 2000$
			$Q_{tzk,t} \geq 5000$	4000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50000$	$Q_{gpt,t} < 3000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{gpt,t}+ 2000$
			$Q_{gpt,t} \geq 3000$	2500			

Table S6. Multi reservoir joint flood control operation Scheme 4 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Instream (m³/s)	Impound Flow (m³/s)	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 4000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 49{,}700$	$Q_{jz,t} + 2000$
			$Q_{jz,t} \geq 4000$	4000			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 5000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{ylj,t} + 2000$
			$Q_{ylj,t} \geq 5000$	3500			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}000$	$Q_{xx,t} + 2000$
		$Q_{sx,t+2} < 68{,}200$	-	3000			
		$Q_{sx,t+2} < 75{,}000$	-	8000			
		$Q_{sx,t+2} \geq 75{,}000$	-	11,000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 2000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 46{,}000$	$Q_{pbg,t} + 2000$
			$Q_{pbg,t} \geq 2000$	$(Q_{pbg,t} - 2000)/2 + 1500$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 6500$	2400	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}100$	$Q_{tzk,t} + 500$
			$Q_{tzk,t} \geq 6500$	4000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,} < 3000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 50{,}000$	$Q_{gpt,t} + 500$
			$Q_{gpt,t} \geq 3000$	2000			

Table S7. Multi reservoir joint flood control operation Scheme 5 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water level of TGR （m）	Instream of TGR(m³/s)	Reservoir instream (m³/s)	Impound flow (m³/s)	Water level of TGR （m）	Instream of TGR(m³/s)	Reservoir discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 4000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{jz,t} + 2000$
			$Q_{jz,t} \geq 4000$	2500			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 4000$	1600	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{ylj,t} + 2000$
			$Q_{ylj,t} \geq 4000$	3500			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}000$	$Q_{xx,t} + 2000$
		$Q_{sx,t+2} < 62{,}300$	-	5000			
		$Q_{sx,t+2} < 75{,}000$	-	5500			
		$Q_{sx,t+2} \geq 75{,}000$	-	11000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 2000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 49{,}100$	$Q_{pbg,t} + 1800$
			$Q_{pbg,t} \geq 2000$	$(Q_{pbg,t} - 2000)/2 + 600$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 6500$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{tzk,t} + 2000$
			$Q_{tzk,t} \geq 6500$	4400			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 3000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 49{,}200$	$Q_{gpt,t} + 1300$
			$Q_{gpt,t} \geq 3000$	2000			

Table S8. Multi reservoir joint flood control operation Scheme 6 in the upper reach of Yangtze River.

Reservoir	Conditions of beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR (m)	Instream of TGR(m³/s)	Reservoir Instream (m³/s)	Impound Flow (m³/s)	Water Level of TGR (m)	Instream of TGR(m³/s)	Reservoir Discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 6000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{jz,t} + 1300$
			$Q_{jz,t} \geq 6000$	2500			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 4000$	1000	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{ylj,t} + 2000$
			$Q_{ylj,t} \geq 4000$	3000			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}000$	$Q_{xx,t} + 4000$
		$Q_{sx,t+2} < 60{,}000$	-	3800			
		$Q_{sx,t+2} < 80{,}000$	-	8000			
		$Q_{sx,t+2} \geq 80{,}000$	-	11000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 4000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 46{,}000$	$Q_{pbg,t} + 500$
			$Q_{pbg,t} \geq 4000$	$(Q_{pbg,t} - 4000)/2 + 1100$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 7000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{tzk,t} + 900$
			$Q_{tzk,t} \geq 7000$	4000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 4000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{gpt,t} + 2000$
			$Q_{gpt,t} \geq 4000$	2000			

Table S9. Multi reservoir joint flood control operation Scheme 7 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Instream (m³/s)	Impound Flow (m³/s)	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 156$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 6000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 47{,}100$	$Q_{jz,t} + 1200$
			$Q_{jz,t} \geq 6000$	2800			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 158$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 4500$	2500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{ylj,t} + 500$
			$Q_{ylj,t} \geq 4500$	3500			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 155$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}100$	$Q_{xx,t} + 2000$
		$Q_{sx,t+2} < 70{,}000$	-	4700			
		$Q_{sx,t+2} < 78{,}200$	-	8000			
		$Q_{sx,t+2} \geq 78{,}200$	-	9000			
Pubugou	$Z_{sx,t} \geq 158$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 4000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 50{,}000$	$Q_{pbg,t} + 500$
			$Q_{pbg,t} \geq 4000$	$(Q_{pbg,t} - 4000)/2+1500$			
Tingzikou	$Z_{sx,t} \geq 148$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 5000$	4000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 48{,}400$	$Q_{tzk,t} + 1100$
			$Q_{tzk,t} \geq 5000$	5000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 3000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 50{,}000$	$Q_{gpt,t} + 500$
			$Q_{gpt,t} \geq 3000$	2500			

Table S10. Multi reservoir joint flood control operation Scheme 8 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water Level of TGR (m)	Instream of TGR(m^3/s)	Reservoir Instream (m^3/s)	Impound Flow (m^3/s)	Water level of TGR (m)	Instream of TGR(m^3/s)	Reservoir Discharge(m^3/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 4000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 46{,}000$	$Q_{jz,t} + 2000$
			$Q_{jz,t} \geq 4000$	2500			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 5000$	2500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 50{,}000$	$Q_{ylj,t} + 2000$
			$Q_{ylj,t} \geq 5000$	3500			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 46{,}700$	$Q_{xx,t} + 3800$
		$Q_{sx,t+2} < 60{,}000$	-	3000			
		$Q_{sx,t+2} < 80{,}000$	-	8000			
		$Q_{sx,t+2} \geq 80{,}000$	-	9000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 3700$	1100	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 46{,}000$	$Q_{pbg,t} + 2000$
			$Q_{pbg,t} \geq 3700$	$(Q_{pbg,t} - 3700)/2 + 500$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 7000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 50{,}000$	$Q_{tzk,t} + 500$
			$Q_{tzk,t} \geq 7000$	4000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 3000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 46{,}000$	$Q_{gpt,t} + 500$
			$Q_{gpt,t} \geq 3000$	2000			

Table S11. Multi reservoir joint flood control operation Scheme 9 in the upper reach of Yangtze River.

Reservoir	Conditions of Beginning Impound Flood		Strategy of Impound Flood		Strategy of Reservoir Discharge		
	Water level of TGR（m）	Instream of TGR(m³/s)	Reservoir Instream (m³/s)	Impound Flow (m³/s)	Water Level of TGR（m）	Instream of TGR(m³/s)	Reservoir Discharge(m³/s)
Cascade reservoir in the middle of Jinsha River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{jz,t} < 5000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 4{,}8000$	$Q_{jz,t} + 1000$
			$Q_{jz,t} \geq 5000$	2000			
Cascade reservoir in the Yalong River	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{ylj,t} < 4000$	1500	$Z_{sx,t} < 158$	$Q_{sx,t+3} < 4{,}8000$	$Q_{ylj,t} + 1000$
			$Q_{ylj,t} \geq 4000$	2000			
Cascade reservoir Lower reaches of the Jinsha River	$Z_{sx,t} \geq 158$	$Q_{sx,t+2} < 50{,}000$	-	0	$Z_{sx,t} < 158$	$Q_{sx,t+2} \leq 4{,}8000$	$Q_{xx,t} + 3000$
		$Q_{sx,t+2} < 60{,}000$	-	4000			
		$Q_{sx,t+2} < 70{,}000$	-	6000			
		$Q_{sx,t+2} \geq 70{,}000$	-	10000			
Pubugou	$Z_{sx,t} \geq 145$	$Q_{sx,t+3} \geq 50{,}000$	$Q_{pbg,t} < 3000$	500	$Z_{sx,t} < 158$	$Q_{sx,t+3} \leq 48{,}000$	$Q_{pbg,t} + 1000$
			$Q_{pbg,t} \geq 3000$	$(Q_{pbg,t} - 3000)/2 + 1000$			
Tingzikou	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{tzk,t} < 6000$	2000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 48{,}000$	$Q_{tzk,t} + 1000$
			$Q_{tzk,t} \geq 6000$	3000			
Goupitan	$Z_{sx,t} \geq 145$	$Q_{sx,t+1} \geq 50{,}000$	$Q_{gpt,t} < 3000$	1000	$Z_{sx,t} < 158$	$Q_{sx,t+1} \leq 48{,}000$	$Q_{gpt,t} + 1000$
			$Q_{gpt,t} \geq 3000$	2000			

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