Supplementary Information

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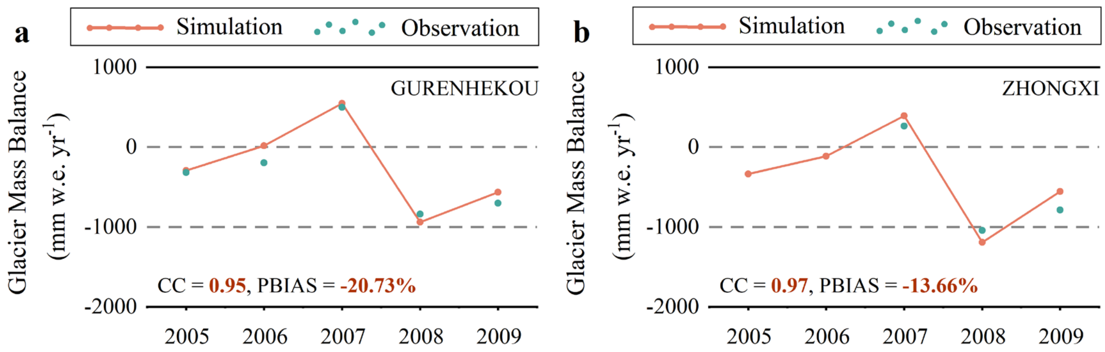
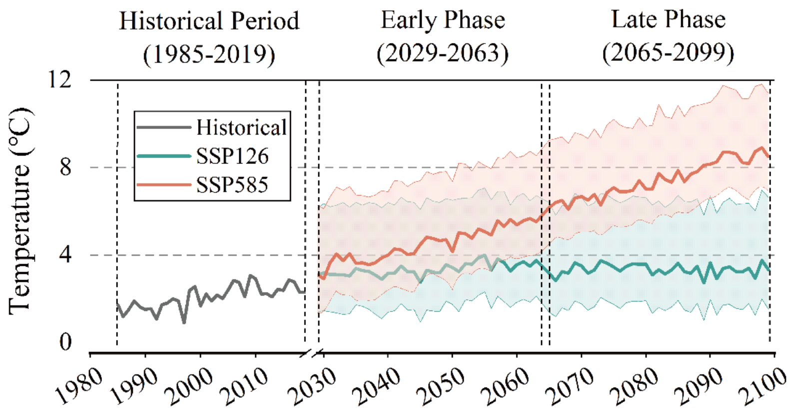
1. Supplementary Figures (S1-S2)



Supplementary Figure S1 Validations of the glacier mass balance by the GURENHEKOU(a) and the ZHONGXI(b) Glaciers. The simulated (pink-dotted dot solid lines) and observed (blue dots) annual data for the glacier mass balances in the GURENHEKOU and the ZHONGXI glaciers.



Supplementary Figure S2 Temperature variability under the climate scenarios. The grey line represents the annual average temperature in the historical period (1985-2019). The pink solid line represents the temperature in five selected GCMs under SSP585 in the early (2029-2063) and late (2065-2099) phases. The upper pink line represents the maximum temperature, while the lower pink line shows the minimum temperature. The blue solid line depicts the temperature under SSP126. The upper blue line represents the maximum values, and the lower line shows the minimum values.

2. Supplementary Tables (S1-S5)

Supplementary Table S1 The performance of runoff simulation at the representative hydrological stations

Hydrological stations	Time Scale	Calibration period		Validation period		Full period	
		Monthly: 1985-2003		Monthly: 2003-2019 Daily: 2003-2019 2017-2019 (Dexing)		Monthly: 1985-2019 Daily: 2003-2019 2017-2019 (Dexing)	
		NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
Yuncun	Monthly	0.79	-0.2%	0.77	1.5%	0.79	0.3%
Nuxia		0.88	3.0%	0.91	-0.4%	0.89	1.8%
Dexing		/		0.86	1.8%	0.86	1.8%
Nuxia	Daily	/		0.88	-0.4%	0.88	-0.4%
Dexing				0.75	4.7%	0.75	4.7%

Supplementary Table S2 Selected points in the middle of the Pareto bounds of the different reservoir replenishment flows

FlowSize (m^3/s)	HP (kWh)	EI (-)	EI RepR	EI RRU	EI RRD	EI BR	Fp (%)	Fp RepR	Fp RRU	Fp RRD	Fp BR
600	2213.0	0.36	0.25	0.74	0.35	0.10	22.06	16.24	42.62	23.58	5.78
800	2229.2	0.43	0.38	0.72	0.38	0.25	22.80	18.39	41.14	25.55	6.12
1000	2231.4	0.45	0.48	0.69	0.35	0.27	22.82	18.55	40.98	25.65	6.25
1200	2249.6	0.55	0.63	0.75	0.42	0.40	24.17	21.70	40.52	26.88	7.59
1400	2262.9	0.59	0.71	0.73	0.43	0.48	23.99	21.67	39.72	26.92	7.65

Supplementary Table S3 Selected points in the middle of the Pareto bounds under climate change and hydropower development

Scenario	HP	EI	EI				Fp	Fp			
-	$\times 10^8$kWh	-	RepR	RRU	RRD	BR	(%)	RepR	RRU	RRD	BR
Historical	2231.4	0.45	0.48	0.69	0.35	0.27	22.82	18.55	40.98	25.65	6.25
SSP126-EP	2406.2	0.50	0.64	0.67	0.38	0.31	29.18	27.91	41.47	31.23	16.13
SSP126-LP	2413.1	0.50	0.65	0.67	0.39	0.30	22.26	19.25	34.21	25.03	10.56
SSP558-EP	2502.3	0.53	0.71	0.67	0.39	0.33	13.53	5.83	25.14	18.59	4.57
SSP558-LP	2736.7	1.06	1.25	1.14	0.96	0.89	11.00	-4.98	24.33	20.03	4.62

Supplementary Table S4 The input and output datasets of the WEP-L model

Variable	Dataset	Temporal Resolution	Spatial Resolution
Gauged meteorological data (precipitation, temperature, relative humidity, wind speed and solar radiation)	China Meteorological Administration and Corrected ERA5: only for precipitation [1]	Daily	Site, 0.1°
DEM	Geospatial Data Cloud (http://www.gscloud.cn)	-	1000m
Soil type	Resource and Environment Cloud Platform of the Chinese Academy of Sciences (CAS)	-	1000m
Landuse	Chinese Academy of Sciences	per 5 years	1000m
Glacier	1st & 2nd Chinese Glacier Inventory [2,3,4]	-	Polygons
Snow Cover (fraction)	National Tibetan Plateau Data Center (https://dx.doi.org/10.11888/Snow.tpdc.271381)	Daily	0.05°
Observed and Reconstructed glacier mass balance	World Glacier Monitoring Service (https://wgms.ch/) and [5]	Annual	Site
Observed streamflow	Hydrological Bureau, Ministry of Water Resources, P.R. China	Monthly, Daily	Site

Supplementary Table S5 The contribution rate of the principal components

Component	Initial Eigenvalues (IEs)			
	IE	Representative parameter	% of Original Variance	Corrected (w_p, %)
1	19.18	Mean flow in Nov.	59.9	68.3
2	4.46	1-day maximum	13.9	15.9
3	1.37	High pulse count	4.3	4.9
4	1.22	Date max	3.8	4.3
5	1.18	Date min	3.1	3.5
6	1.08	Mean flow in June	2.8	3.1
Total			87.8	100

3. Operation Rules and Constraints of the first reservoir

3.1 Water balance constraint

$$84600Q_{in,i} + S_{i-1} = 84600Q_{out,i} + S_i \,(1); \quad H_i = aS_i + b\,(2);$$

Where $Q_{in,i}$ and $Q_{out,i}$ denote the net inflow and outflow to the reservoir on the ith day (m^3/s); H_i denotes the reservoir water level on the ith day (m); a and b are parameters of the reservoir water stage-storage curve; S_{dead} denotes the dead water storage (m^3); Eqs. 1-2 represent the water balance constraint and water stage-storage curve, respectively.

3.2 Maximum storage constraint

$$S_i \le S_{\max}\,(3); \quad S_{\max} = S_{total}\,(4); \quad Q_{out} = \left\{Q_{cp}, Q_{ab}\right\}_{min}\,(5);$$

Where S_{i-1} and S_i denote the volumes of ending water storage on day i and day $i-1$ (m^3); S_{max} denotes the maximum water storage (m^3) and S_{total} denotes the reservoir storage capacity (m^3); Q_{cp} denotes the outflow of the reservoir storage overtaking the maximum storage constraint (m^3/s); Q_{ab} denotes the maximum discharge capacity (m^3/s).

3.3 Minimum storage constraint

$$S_{\mathrm{i}} \ge S_{\mathrm{dead}}\,(6); \quad S_{dead} = 0.10S_{total}\,(7); \quad Q_{out} = \begin{cases} Q_{in}, Q_{in} < Q_{e-flow} \\ Q_{e-flow}, other \end{cases} \,(8);$$

Where S_{dead} denotes the dead water storage (m^3); $Q_{e\text{-}flow}$ denotes the discharge with the e-flow constraint of the reservoir.

3.4 Environmental flow constraint

$$Q_{out,t} \ge Q_{e-flow}\,(9); \; Q_{e\text{-}flow}=10\%Q_{avg}\,(10)$$

where $Q_{out,t}$ denotes the outflow of the reservoir in the tth month (m^3/s). As per "*Guidelines for Water Resources Assessment of Water Resources and Hydropower Construction Projects*" [6] and the scheduled reservoir operating protocols, the Environmental flow ($Q_{e\text{-}flow}$) is set at 10% of the natural runoff (Eq.10).

4. Eco-index (EI) Calculation

4.1 Components of IHA parameters

The IHA contains 33 hydrologic parameters that can generally be categorized into five groups: (1) magnitude of monthly water calendar, (2) magnitude and duration of annual extreme water conditions, (3) timing of annual extreme water conditions, (4) frequency and duration of high and low pulses, and (5) rate and frequency of water condition changes (Table S5) [7]. The number of zero flow events was not considered in this research because there was no outage in the YT river during the historical period.

Supplementary Table S5 Five groups of the IHA parameters

IHA statistics	Hydrologic parameters	
Group 1	Mean flow in January	Mean flow in July
	Mean flow in February	Mean flow in August
	Mean flow in March	Mean flow in September
	Mean flow in April	Mean flow in October
	Mean flow in May	Mean flow in November
	Mean flow in June	Mean flow in December
Group 2	1-day minimum	1-day maximum
	3-day minimum	3-day maximum
	7-day minimum	7-day maximum
	30-day minimum	30-day maximum
	90-day minimum	90-day maximum
	Base flow index	
Group 3	Date of minimum	Date of maximum
Group 4	Low pulse count	High pulse count
	Low pulse duration	High pulse duration
Group 5	Rise rate	Number of Reversals
	Fall rate	

4.2 Representation and Weight Coefficient

The PCA method was used to identify representative indicators for operational purposes and the results are shown in Table S1 and Table S6 [8]. Six parameters were chosen according to the Kaiser–Guttman criterion [9]: Mean flow in November, 1-day maximum, High pulse count, Date of maximum, Date of minimum and Mean flow in June. The EI weight coefficients wp in Eq. (4) were set based on the contribution rate of each PC. They were 0.683, 0.159, 0.049, 0.043, 0.035 and 0.031, respectively. The results show that the mean flow in November was the most significant ecological parameter in this basin, explaining 68.3% of the variation. It is worth noting that the first six PCs explained 87.8% of the variation.

Supplementary Table S6 Factor loading rate of each IHA indicator in PCA

Parameter		PC1	PC2	PC3	PC4	PC5	PC6
Group 1	Mean flow in May	0.082	0.010	0.075	0.006	-0.010	0.047
	Mean flow in June	-0.039	0.035	-0.063	-0.052	0.053	**0.863**
	Mean flow in July	0.049	-0.001	0.327	-0.154	-0.039	0.098
	Mean flow in August	0.025	0.185	-0.086	-0.077	0.066	0.010
	Mean flow in September	0.026	0.078	0.035	0.187	0.000	0.002
	Mean flow in October	0.045	-0.023	0.146	0.413	-0.083	0.002
	Mean flow in November	**0.179**	-0.049	0.225	0.119	-0.071	0.096
	Mean flow in December	0.148	0.007	0.039	-0.011	-0.035	-0.012
	Mean flow in January	0.147	0.034	0.001	0.002	0.067	0.003
	Mean flow in February	0.147	0.034	0.001	0.007	0.062	0.004
	Mean flow in March	0.149	0.034	0.014	-0.010	0.052	0.019
	Mean flow in April	0.152	0.013	0.064	0.008	0.055	0.012
Group 2	1-day minimum	0.078	0.021	0.013	-0.016	-0.068	-0.007
	3-day minimum	0.078	0.022	0.013	-0.016	-0.065	-0.007
	7-day minimum	0.078	0.021	0.014	-0.018	-0.059	-0.006
	30-day minimum	0.077	0.019	0.020	-0.014	-0.020	-0.007
	90-day minimum	0.077	0.025	0.013	-0.003	0.024	-0.002
	1-day maximum	0.034	**0.234**	-0.166	-0.073	0.034	-0.027
	3-day maximum	0.033	0.233	-0.166	-0.071	0.035	-0.025
	7-day maximum	0.031	0.230	-0.163	-0.062	0.037	-0.016
	30-day maximum	0.029	0.198	-0.100	-0.008	0.062	0.040
	90-day maximum	0.035	0.142	0.017	0.012	0.034	0.021
	Base flow index	0.052	-0.006	-0.015	-0.044	-0.021	-0.015
Group 3	Date of minimum	-0.002	0.056	-0.014	0.073	**0.962**	0.040
	Date of maximum	-0.035	-0.025	-0.177	**0.645**	0.145	-0.071
Group 4	Low pulse count	-0.052	-0.012	0.017	0.018	0.025	-0.047
	Low pulse duration	-0.086	-0.019	-0.068	-0.006	-0.046	0.035
	High pulse count	-0.070	0.055	**-0.446**	0.085	-0.098	0.197
	High pulse duration	0.067	-0.057	0.433	-0.019	-0.011	-0.136
Group 5	Rise rate	-0.053	-0.078	0.118	0.167	-0.119	0.324
	Fall rate	0.021	0.090	-0.255	-0.060	0.044	-0.200
	Number of Reversals	0.060	0.030	-0.041	0.006	0.040	-0.172

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