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Irrigation, damming, and streamflow fluctuations of the Yellow River

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A The Nash-Sutcliffe Efficiency (NSE) is incomparable between natural discharge simulations and regulated discharge simulations

Assuming that N_i is the time series of natural discharge and ΔW_i is water storage change of a reservoir. Thus, the regulated discharge R_i can be calculated as:

$$R_i = N_i - \Delta W_i,$$
$$r_i = n_i - \Delta w_i. \tag{S1}$$

Where i is month index. Capital letters indicate observed variables; while lower case letters indicate simulated variables. Then the NSE of regulated discharge (NSE_1) can be calculated as:

$$\begin{aligned}\mathrm{NSE}_1 &= 1 - \frac{\sum_{i=1}^{M} (R_i - r_i)^2}{\sum_{i=1}^{M} \left(R_i - \bar{R}\right)^2} \\ &= 1 - \frac{\sum_{i=1}^{M} [(N_i - \Delta W_i) - (n_i - \Delta w_i)]^2}{\sum_{i=1}^{M} \left(R_i - \bar{R}\right)^2},\end{aligned} \tag{S2}$$

where M is the length of the time series. Let's assume that the model can give a perfect simulation of water storage change of reservoir. Thus $\Delta w_i = \Delta W_i$ and NSE_1 is,

$$\mathrm{NSE}_1 = 1 - \frac{\sum_{i=1}^{M} (N_i - n_i)^2}{\sum_{i=1}^{M} \left(R_i - \bar{R}\right)^2}. \tag{S3}$$

Note that the NSE of natural discharge (NSE_2) is,

$$\mathrm{NSE}_2 = 1 - \frac{\sum_{i=1}^{M} (N_i - n_i)^2}{\sum_{i=1}^{M} \left(N_i - \bar{N}\right)^2}. \tag{S4}$$

The difference between NSE_1 and NSE_2 is the variation of regulated and natural discharge. As assuming that dam operations always reduce the variation of discharge, the variation of N_i is smaller than R_i. Consequently, NSE_2 is always less than NSE_1. In summary, if reservoirs reduce the variation of river discharge, a model with a perfect dam module will always provide a smaller NSE (with regulated discharge as reference) than that of the model without functions of dam operations (with natural discharge as reference)! The conclusion is that it is not comparable of model (study) performances with different references and that it is not adequate to evaluate dam parameterizations.

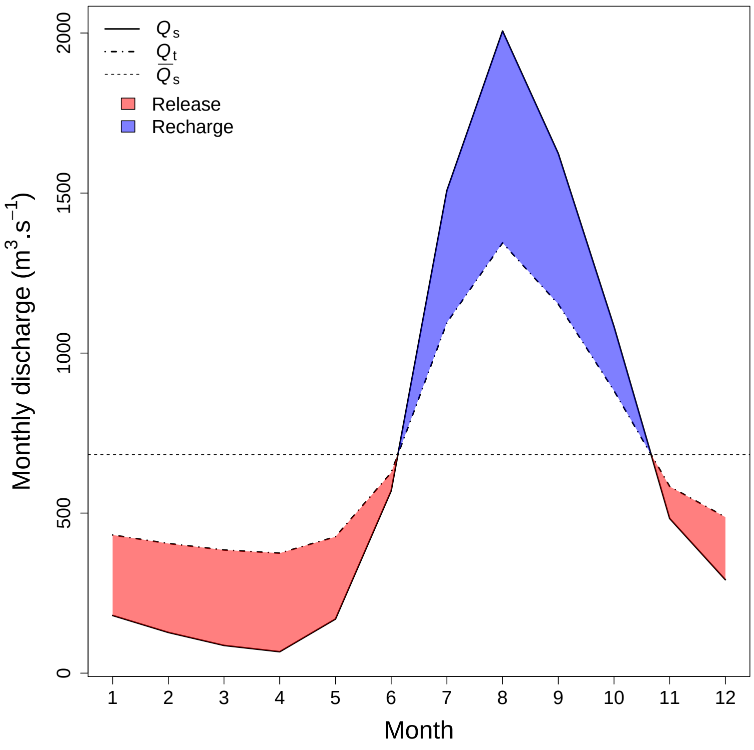

Figure S1. Conceptual plot for the dam operation model. Solid line is multi-year averaged monthly discharge (Q_s, Eq. 1). Solid-dashed line is the targeted monthly discharge (Q_t, Eq. 4). Dashed line is multi-year mean monthly discharge. One year is divided into recharging and releasing season. Blue and red patterns indicate targeted water storage change ΔW_t during the recharging and releasing season, respectively.

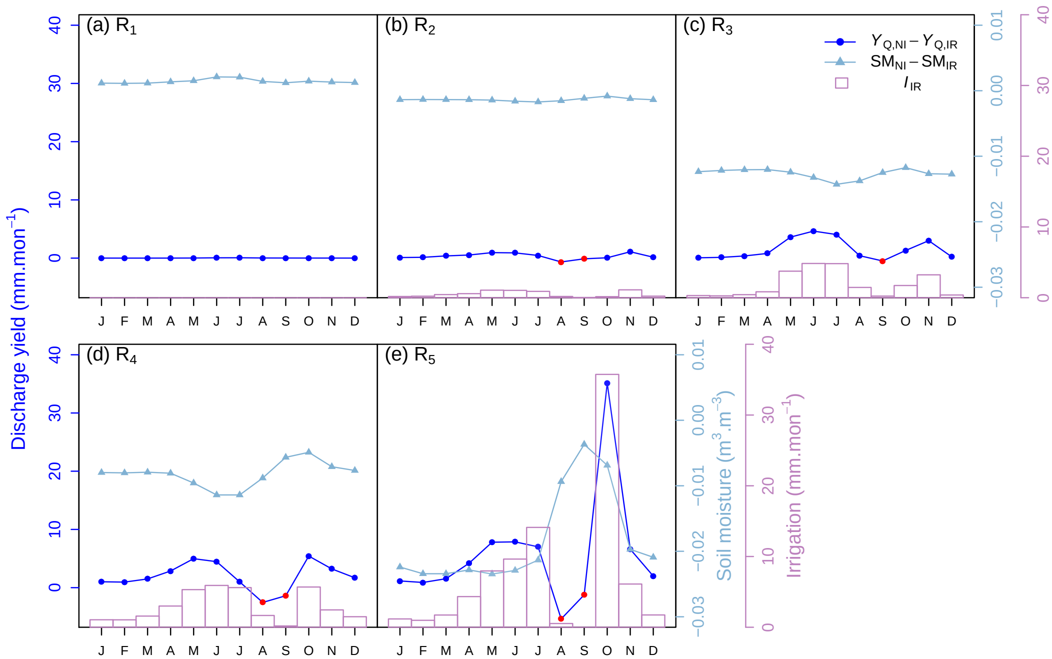

Figure S2. Effects of irrigation on soil moisture (SM) and discharge yield (Y_Q, sum of surface runoff and deep drainage) in each R_i. In the case of Y_Q, negative points are colored red. Purple bars are monthly irrigation based on IR simulation.

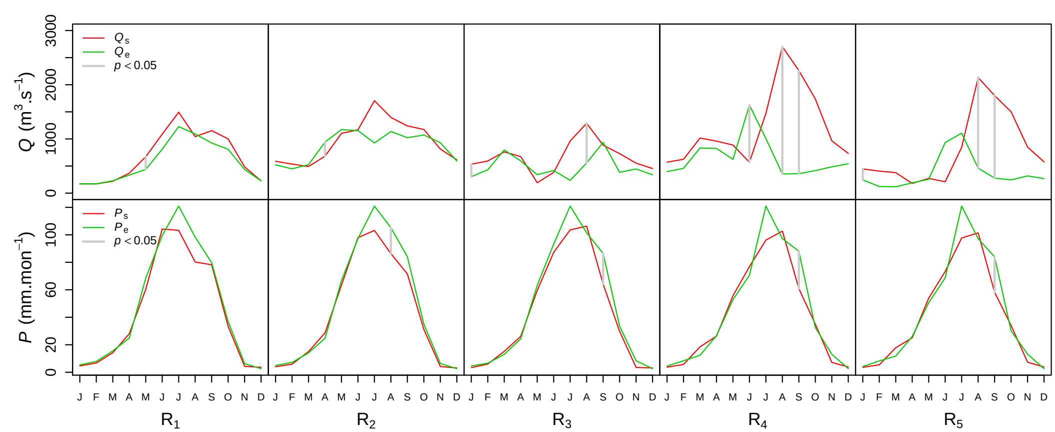

Figure S3. Top panel: changes of observed Q from 1982 to 2014. Red and green lines represent monthly Q at start and end of the diagnosing period based on linear regression. Gray bars indicate significant trends found based on Mann-Kendall test. Sub-figures correspond to specific sub-regions. Bottom panel: same as the top panel but for P from GSWP3 forcing.

Table S1. Validation ORCHIDEE simulated naturalized streamflow against census-based naturalized monthly streamflow of the Yellow River (1982–2000). R^2 is coefficient of determination. mKGE is modified Kling-Gupta Efficiency. d is degree of agreement.

Stations	R^2	mKGE	d
TangNaiHai	0.64	0.67	0.83
LanZhou	0.63	0.33	0.84
HuaYuanKou	0.52	0.18	0.77
LiJin	0.46	0.27	0.75

Table S2. Validation of ORCHIDEE simulated monthly evapotranspiration and transpiration in different sub-catchments of the Yellow River Basin by three data sets. The validation is based on the NI simulation and is applied on each grid cell. The mean and standard deviation of grid cell-based correlation coefficients and relative RMSE are shown below. The relative RMSE is the ratio of RMSE over the mean of observed time series. There is no significant differences in the case of the IR simulation.

Data	Sub-catchments	Evapotranspiration		Transpiration	
		Correlation Coefficient	Relative RMSE	Correlation Coefficient	Relative RMSE
GLEAM	R_1	0.84±0.05	4.2±0.6%	0.72±0.11	8.0±3.7%
	R_2	0.88±0.04	3.8±0.8%	0.79±0.09	7.6±2.8%
	R_3	0.89±0.02	4.4±0.9%	0.81±0.07	9.6±3.1%
	R_4	0.92±0.01	3.2±0.9%	0.84±0.03	6.1±2.7%
	R_5	0.91±0.02	2.7±0.3%	0.71±0.06	5.2±0.5%
FLUXCOM	R_1	0.86±0.03	3.8±0.5%	–	–
	R_2	0.93±0.04	3.1±0.9%	–	–
	R_3	0.84±0.10	4.5±1.5%	–	–
	R_4	0.93±0.04	3.3±1.3%	–	–
	R_5	0.88±0.03	3.8±0.5%	–	–
PKU	R_1	0.92±0.04	3.8±1.3%	–	–
	R_2	0.93±0.03	3.5±1.5%	–	–
	R_3	0.87±0.04	4.3±1.2%	–	–
	R_4	0.88±0.04	3.8±1.0%	–	–
	R_5	0.79±0.04	4.9±0.5%	–	–