Cover letter

Dear professor Murugesu Sivapalan:

We greatly appreciate you and the reviewers for taking time to review this manuscript and provide us with constructive and valuable comments. As reviewer 3 showed major concerns on the model conceptualization (particularly for socioeconomic projection) and the discordant scale of WEFS nexus, we have devoted ourselves to improve corresponding sections in Method and Discussion: (1) we applied Logistic model for socioeconomic projection in WEFS nexus as reviewer 3 recommended, and differences between the results of Malthusian model and Logistic model were discussed in the revised manuscript; (2) weight factors for water, energy, and food shortage awareness were added, the sensitivity analysis on which was conducted to investigate the contributions to environmental awareness from water, energy, and food systems with discordant scale. We believe the manuscript has been much improved. Our changes are marked in Blue in the revised manuscript. And our responses to the reviewers are detailed in this response-to-reviewers document submitted with the revised manuscript.

If you have any queries, please don't hesitate to contact me at the address below.

Looking forward to hearing from you.

Sincerely,

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Reviewer1

The authors have made substantial revisions to the manuscript, and most of my concerns are addressed or clarified. I only have three very minor suggestions that I think the authors should further do to improve their paper.

Thank you for your positive feedback and valuable comments on our paper. We have carefully revised our manuscript according to the comments. Here are the responses to your comments:

1) It is misleading to simply write "scenario I, scenario II …" in the abstract. Readers will not understand what these scenarios are, without reading the whole paper. Therefore, the authors should replace "scenario I, scenario II …" with some specific description languages.

1. Response:

Thanks for your supportive comment. We have added specific description about scenarios in abstract in line 32~37.

"The annual average energy shortage rate thereby decreased from 17.16% to 5.80% by taking environmental awareness feedback, contributing to the sustainability of the WEFS nexus. Rational water resources allocation can ensure water supply through reservoir operation. The annual average water shortage rate decreased from 15.89% to 7.20% as water resources allocation was considered."

2) Some of my comments should be better clarified in the main text instead of just in the Response document. For example, the definition of environmental carrying capacity should be given in the manuscript Line 179.

2. Response:

Thanks for your supportive comment. We have checked the manuscript and added the definition in line 180~182. "environmental carrying capacities of socioeconomic variables (indicating the maximum socioeconomic size that can be carried by the system)"

3) After two rounds of revision, the current version of the manuscript is a bit too long. Maybe it is better to move some of the contents, such as Table 1, to a supplementary document. And the language can be more concise throughout the manuscript.

3. Response:

Thanks for your supportive comment. We have added a supplementary document to simplify the manuscript, including tables for reservoir characteristics, and the calibrated parameters, and figures for sensitivity analysis of shortage awareness weight factors.

Reviewer 3

Though the authors have clearly invested time developing this manuscript, I still believe that it does not meet the standards of publication in this journal. Ultimately, as stated in the first review comments, for an abstract model which cannot be validated with real-world data, trustworthy insights require a well-reasoned model conceptualization. Major issues are still present with the model formulation and presentation, and the abundance of issues captured throughout the review process does not inspire confidence that the model will reach a reliable form.

Thank you very much for your critical but supportive comments, from which we have benefited a lot. We have tried hard to investigate the reliability of model conceptualization, and the discordant scale of WEFS nexus. Here are the responses to your comments:

Lines 170-182 and equations 2-4:

I maintain that a logistic model (sometimes called a Verhulst model) is more appropriate than the model proposed here. In a logistic model, proximity to the carrying capacity slows down growth (or exceeding the carrying capacity causes decay) rather than *time* slowing down growth. Why should time inherently slow growth? For instance, this oversight would seem to be the reason that population, GDP, etc. never resume growing after the year 2050.

1. Response:

Thanks for your supportive comment. We agree that logistic model is also popular in growth simulation for socioeconomic sector, as is claimed in the first round response. To quantitatively assess the differences between the Malthusian model and the Logistic model, **we applied Logistic model for WEFS nexus simulation**.

Model conceptualization for Logistic model was added in line 173~189.

"There are two types of methods which are popular in socioeconomic projection, Malthusian model (Bertalanffy, 1976; Malthus, 1798) and Logistic model (Law et al., 2003), which are adopted for the socioeconomic projection. The growth rate in original Malthusian model is constant (Malthus, 1798), which is not consistent with previous studies that the socioeconomic expansion in the future would slow down (He et al., 2017; Lin et al., 2016). Therefore, we used exponential terms to simulate the evolution of socioeconomic variables, which increases with decreasing rate. And feedback functions, as well as environmental carrying capacities (indicating the maximum socioeconomic size that can be carried by the system) of socioeconomic variables are adopted to constrain the evolution of these socioeconomic variables through equations (2)–(4) (Feng et al., 2016; Hritonenko and Yatsenko, 1999). Socioeconomic factors in original Logistic model (Law et al., 2003) are prone to approach to their environmental carrying capacities, while the constrains among subsystems in WEFS nexus are typically neglected, which will lead over-sized socioeconomic projection. Therefore, feedback functions taken as constraints from subsystems are adopted in equation (5)–(7) (Li et al., 2019; Wu et al., 2022)."

$$\begin{cases} \dfrac{dN_t}{dt} = r_{P,t} * N_t \\ r_{P,t} = \begin{cases} r_{P,0} * \kappa_P * \exp(-\varphi_P t) + f_1(E) & N_t \le N_{cap} \\ \mathrm{Min}(0, r_{P,0} * \kappa_P * \exp(-\varphi_P t) + f_1(E)) & N_t > N_{cap} \end{cases} \end{cases} \quad (2)$$

$$\begin{cases} \dfrac{dG_t}{dt} = r_{G,t} * G_t \\ r_{G,t} = \begin{cases} r_{G,0} * \kappa_G * \exp(-\varphi_G t) + f_2(E) & G_t \le G_{cap} \\ \mathrm{Min}(0, r_{G,0} * \kappa_G * \exp(-\varphi_G t) + f_2(E)) & G_t > G_{cap} \end{cases} \end{cases} \quad (3)$$

$$\begin{cases} \dfrac{dCA_t}{dt} = r_{CA,t} * CA_t \\ r_{CA,t} = \begin{cases} r_{CA,0} * \kappa_{CA} * \exp(-\varphi_{CA} t) + f_3(E, FA) & CA_t \le CA_{cap} \\ \mathrm{Min}(0, r_{CA,0} * \kappa_{CA} * \exp(-\varphi_{CA} t) + f_3(E, FA)) & CA_t > CA_{cap} \end{cases} \end{cases} \quad (4)$$

$$\frac{dN_t}{dt} = N_t * (r_{P,0} * (1 - \frac{N_t}{N_{cap}}) + f_1(E)) \quad (5)$$

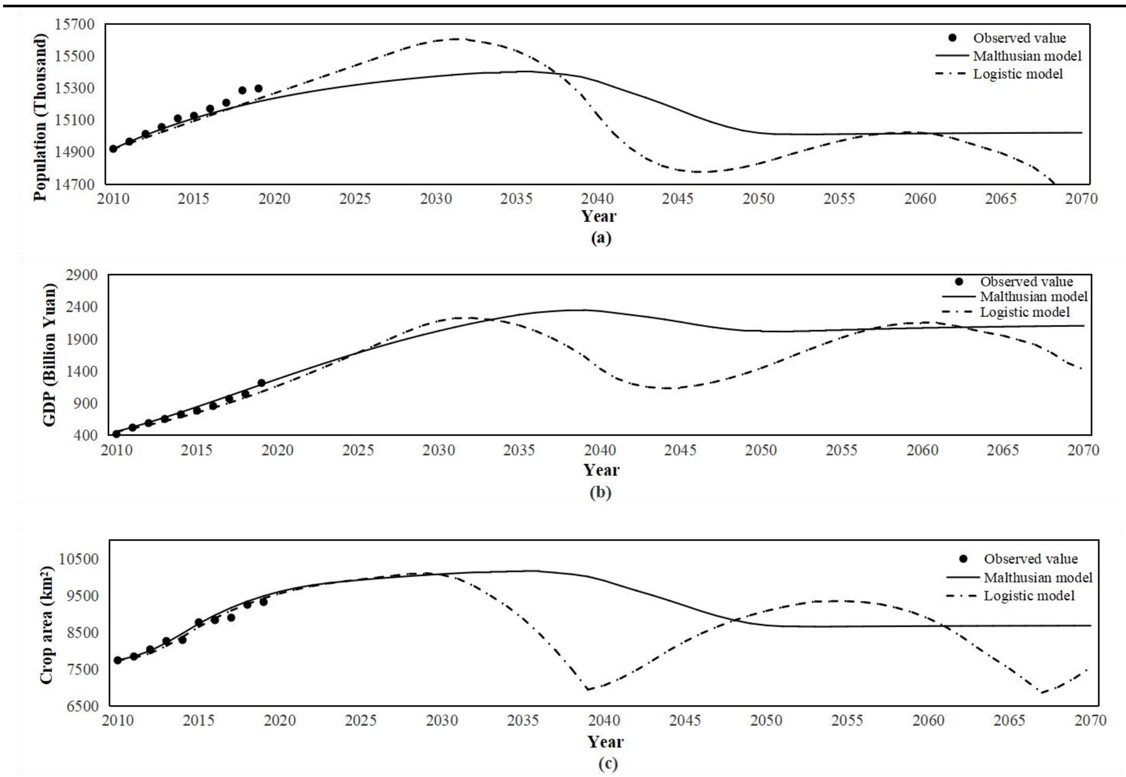
$$\frac{dG_t}{dt} = G_t * (r_{G,0} * (1 - \frac{G_t}{G_{cap}}) + f_2(E)) \quad (6)$$

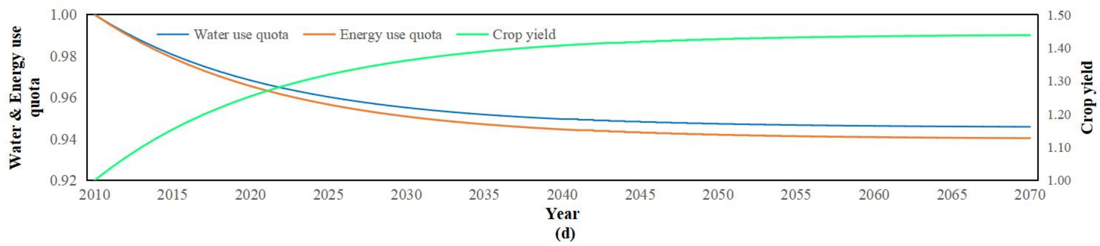
$$\frac{dCA_t}{dt} = CA_t * (r_{CA,0} * (1 - \frac{CA_t}{CA_{cap}}) + f_3(E, FA)) \quad (7)$$

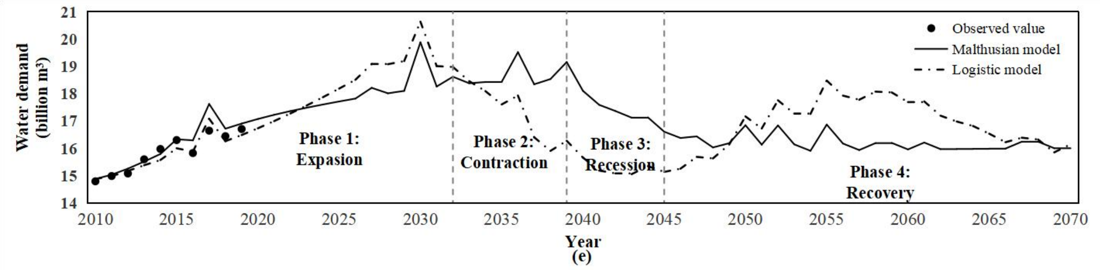
Results and discussion for WEFS nexus co-evolution with Malthusian model and Logistic model were updated in line 465~469, line 498~517, and line 575~593 (shown in Table 2 and Figure 5).

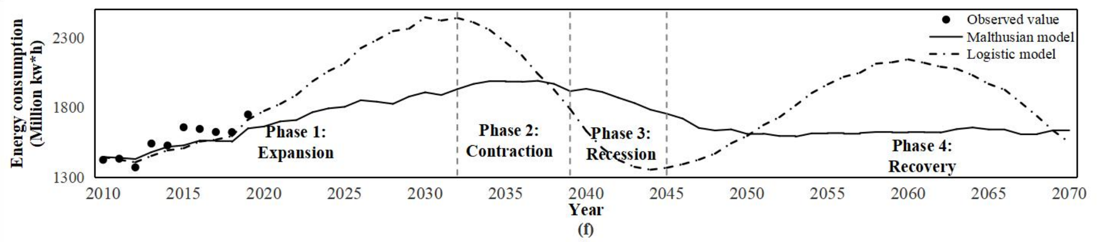
Table 2 NSE and PBIAS of state variables.

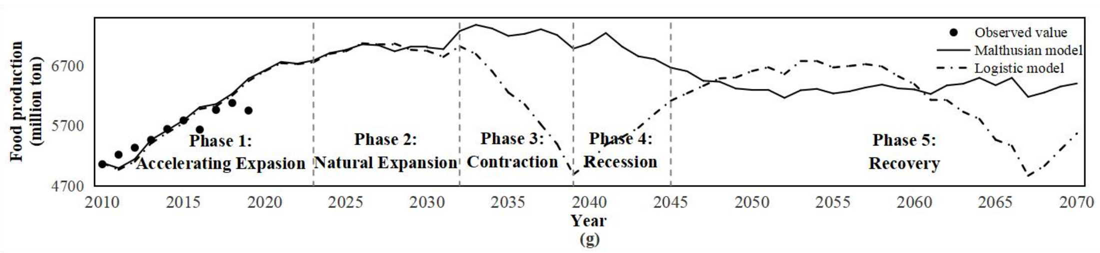
Model	Indicator	Water demand	Energy consumption	Food production	Population	GDP	Crop area
Malthusian model	NSE	0.91	0.74	0.79	0.97	0.86	0.94
	PBIAS (%)	-0.7	1.9	-0.6	-4.2	0.2	-0.8
Logistic model	NSE	0.79	0.74	0.82	0.94	0.85	0.96
	PBIAS (%)	-1.0	2.0	-0.2	5.2	0.3	-0.1

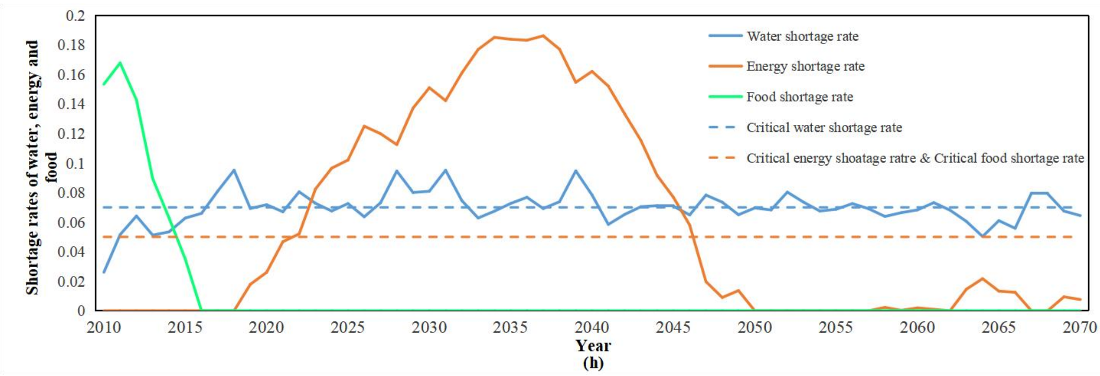



Water use quota
Energy use quota
Crop yield
Water & Energy use quota
Crop yield
Year
(d)


Observed value
Malthusian model
Logistic model
Water demand (billion m³)
Phase 1: Expasion
Phase 2: Contraction
Phase 3: Recession
Phase 4: Recovery
Year
(e)


Observed value
Malthusian model
Logistic model
Energy consumption (Million kw*h)
Phase 1: Expansion
Phase 2: Contraction
Phase 3: Recession
Phase 4: Recovery
Year
(f)


Observed value
Malthusian model
Logistic model
Food production (million ton)
Phase 1: Accelerating Expasion
Phase 2: Natural Expansion
Phase 3: Contraction
Phase 4: Recession
Phase 5: Recovery
Year
(g)


Water shortage rate
Energy shortage rate
Food shortage rate
Critical water shortage rate
Critical energy shoatage ratre & Critical food shortage rate
Shortage rates of water, energy and food
Year
(h)

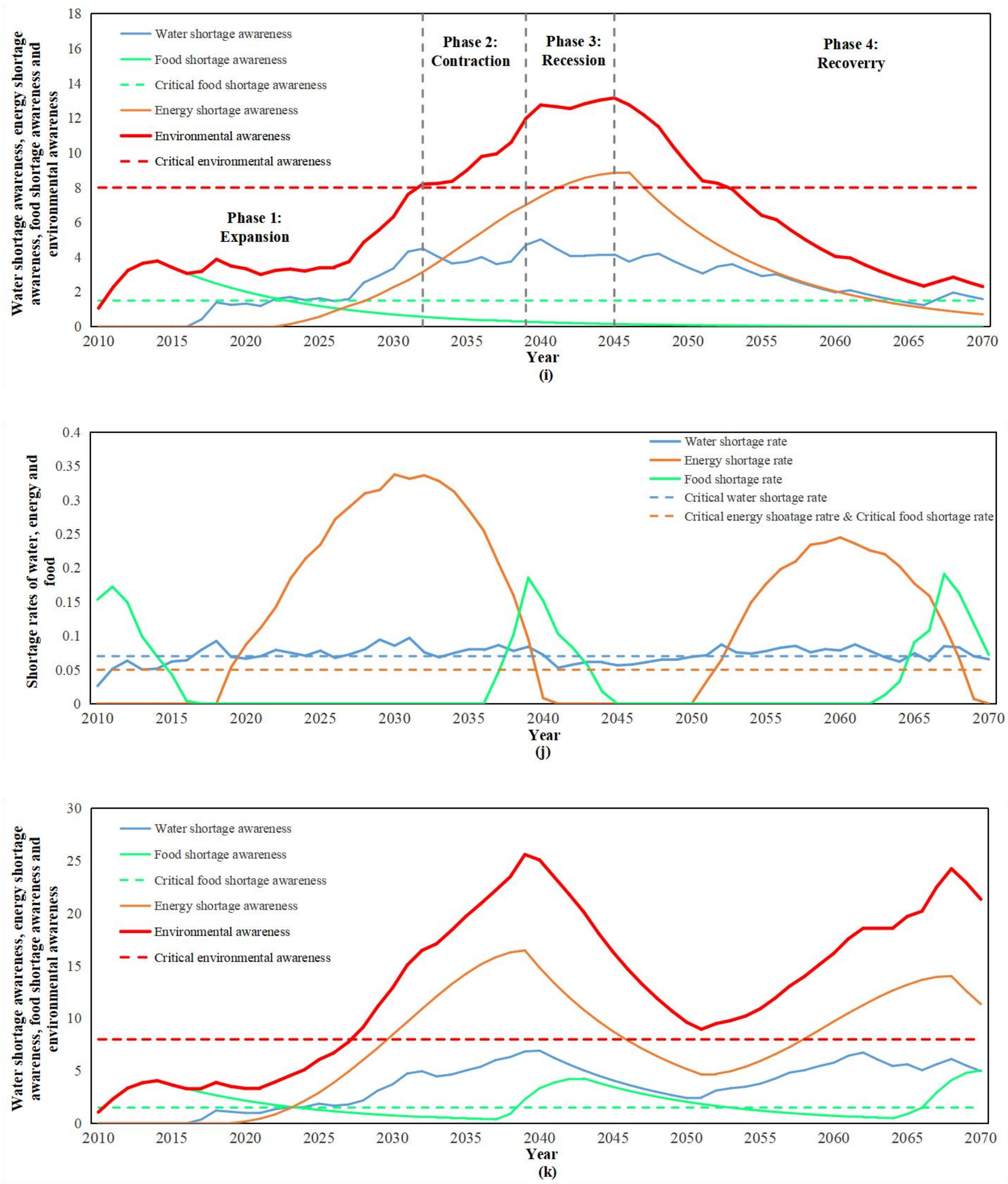


Figure 5. Trajectories of state variables in WEFS nexus: (a) population; (b) GDP; (c) crop area; (d) percentage variations (compared with initial values) of water use quota, energy use quota, and crop yield; (e) water demand; (f) energy consumption; (g) food production; (h) shortage rates of water, energy, and food in Malthusian model; (i) water shortage awareness, energy shortage awareness, food shortage awareness, and environmental awareness in Malthusian model; (j) shortage rates of water, energy, and food in Logistic model; (k) water shortage awareness, energy shortage awareness, food shortage awareness, and environmental awareness in Logistic model.

As shown in Table 2, the NSEs range from 0.74 to 0.97, and the corresponding PBIASs are from -4.2% to 5.2%, indicating that both Malthusian model and Logistic model can effectively fit the observed data of WEFS nexus. WEFS nexus co-evolution in Logistic model is interpreted as follow. Socioeconomic sectors kept increasing in the initial phase. The rapid socioeconomic expansion was slowed down until the negative feedback driven by environmental awareness was triggered. With the increasing environmental awareness, socioeconomic recession was followed. Since the decreasing socioeconomic sectors were much lower than their environmental capacities and feedback driven by environmental awareness was weakening, the variables **turned to increase again** to approach to their environmental capacities, and **rolled in cycles**.

For Malthusian model, the socioeconomic variables evolution can be divided into four phases: expansion, contraction, recession, and recovery, as was discussed in the manuscript.

One of the major differences between results of Malthusian model and Logistic model is that state variable evolution in logistic model **fluctuates remarkably and performs periodicity**. However, it's worth noting that the socioeconomic expansion in the future will **slow down and tend to stabilization** (He et al., 2017; Lin et al., 2016), **the growth rate of which will thereby decrease as time goes**. Moreover, the economic development in the study area is also expected to gradually grow and then remains stable according to the Integrated Water Resources Planning of Hanjiang River Basin (CWRC, 2016). As the periodic fluctuation for WEFS nexus evolution through Logistic model is not consistent with the slowed socioeconomic expansion in foreseeable future and cannot fitly satisfy the planning in the study area, Logistic model is not adopted. Malthusian model can fitly meet the demand mentioned above, which is thereby applied for further analysis on WEFS nexus in our study.

Equations 6-8:

Equations 6 and 7 still don’t provide what index is being summed over (only the bounds of summation, 1 to sts-1, are provided), despite mention in the first two rounds of comments. Also, it should be made clear that the variable WE, as formulated in equation 6, is not the natural water inflow during the current time step, but rather the *projected* natural inflow *for the rest of the simulation*.

More importantly, the reasoning behind equation 7 seems seriously flawed: water shortage is defined as the *current* step water demand minus the reservoir inflow from *all preceding steps* minus the natural inflow from *all steps* (preceding and projected to follow), then divided by the remaining time steps. Why is current water shortage not just current demand minus total current supply?

The right-most expression in equation 8 is very unclear – the numerator is summed over two different time indices (ts and sts) yet only one time index is present within the summation (sts). Also, how are the two expressions in equation 8 equivalent? One sums shortages and demands overs all users/districts and the other over all time steps…

2. Response:

Thanks for your supportive comment.

First, as is claimed in line 221~223, in IRAS model, each year is divided into ts time steps, and each time step is further split into sts sub-time steps. Equation (9) and (10) are used to estimate the water shortage of jth water user in ith operational zone during sts sub-time step. Total water shortage in the study area is summed by equation (11).

Second, we agree that the description of “WE” should be clearer. “extrapolated natural water inflow” has been replaced by “projected natural water inflow for the rest $Tsts$-sts+1 sub-time steps” in line 235~244.

Third, water inflow for water user comprises natural water inflow and reservoir release. Specifically, reservoir release is directly related to water shortage from corresponding water users. Directly taking current shortage by deducting total current supply from current demand means that reservoir release in current sub-time step is always related to water shortage in last sub-time step, while the information from natural water inflow is not used. As the temporal distribution of natural water inflow is uneven (i.e., natural water inflow is different in different sub-time step), water supply will be risked, and water resources allocation efficiency will be decreased. Equation (9) and (10) project natural water inflow in the rest sub-time steps based on natural water inflow in previous sub-time steps. Reservoir release in each sub-time step always considers natural water inflow in previous sub-time step, which can effectively improve water resources allocation efficiency.

Fourth, thanks for reminding us. We have corrected equation (11) by summing water user *j* and operational zone *i* in line 242.

$$WSR_t = \frac{\sum_{i,j} WSR_{i,j}^{t}}{f_{red} * \sum_{i,j} WD_{i,j}^{t}} = \frac{\sum_{i,j}\sum_{ts}\sum_{sts} WS_{i,j}^{sts}}{f_{red} * \sum_{i,j}\sum_{ts} WD_{i,j}^{ts}} \quad (11)$$

413-416:

the authors have rephrased the statement and provided the years of data used to assess precipitation frequencies, but have not answered my previous question – how are precipitation frequencies assigned to years within the simulation? That is, how is the time series of future precipitation exceedances constructed? Also, why are all the precipitation exceedance frequencies used above 50% - this doesn't really capture wet years… (despite the text calling 50% "wet" and 75% "normal")

3. Response:

Thanks for your supportive comment.

First, as is claimed in line 413~415, historical discharge series from 1956 to 2016 is adopted, rather than future precipitation. The frequency series is determined by empirical frequency method.

Second, when the precipitation frequency is less than 50%, the year is considered as wet year, and agriculture water use quota with exceedance frequency 50% is adopted for agricultural water demand projection. It means the water demand is over-estimated. More water shortage can be exposed, which **further ensures the water supply safety**.

My prior comment regarding discordant scales where shortages are experienced has not been addressed. The author's response merely restates the information within the manuscript, describing what the scales are. I will try to rephrase my comment: water, energy, and food shortages are all aggregated into one "environmental awareness" variable, however each shortage is experienced by different users with (in reality) different connections to basin development dynamics. Energy users are defined as a sub-set of individuals/firms within the basin, being only those using energy to supply water. Water users are the full set of individuals/firms within the basin. Finally, food users are both within and outside of the basin. So, *shortages* are experienced discordantly by (1) a subset of those within the basin, (2) all those within the basin, and (3) those outside the basin; yet, these shortages are all aggregated into one "environmental awareness". Therefore, via environmental awareness, energy shortage experienced by water suppliers directly constrains crop area; or, food shortage experienced by people living outside the basin directly constrains population growth within the basin. Even if the model formulation is not updated, some acknowledgement and discussion is necessary. Perhaps most concerning, between the first and second versions of the manuscript, the model was reformulated from simulating *all* energy consumption to just energy consumption *by water suppliers*. However, none of the discussion of results was changed. The parameter values were updated and new values for results were pasted in, but none of the substance of discussion was updated. A drastic change in model scope occurred and yet there were no implications for the interpretation of results?

4. Response:

Thanks. We have greatly benefited from this valuable suggestion.

First, we have added the discussion on the impacts of discordant scale on WEFS nexus in line 829~859.

As each shortage is experienced by different users with different connections to basin development dynamics (e.g., shortages from water, energy, and food are aggregated into environmental awareness, despite the food which is planned to be exported is considered in target food production), it's necessary to discuss the contributions to environmental awareness from water, energy, and food systems. Therefore, three weight factors were assigned to shortage awareness of water, energy, and food in equation (32) to adjust the over-estimated or under-estimated environmental awareness due to discordant scales. For instance, considering the target food production comprises inner food demand and exported food, the environmental awareness within the basin is over-estimated, and the weight factor for food shortage awareness can be set lower than 1.0 as a reduction factor to decrease current food shortage awareness. Sensitivity analysis was then conducted. Each weight factor was varied by given increment, while the other two weight factors were set to 1.0 as reference. The results are presented in Figure S1, S2, S3, and S4 in supplemental file.

$$\frac{dE}{dt} = wf_1 * \frac{dWA}{dt} + wf_2 * \frac{dEA}{dt} + wf_3 * \frac{dFA}{dt} \quad (32)$$

where wf_1, wf_2, and wf_3 are the weight factors for water, energy, and food shortage awareness, respectively.

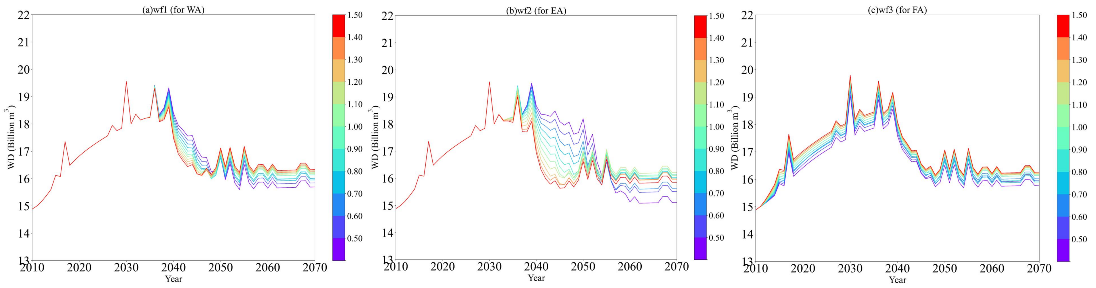


Figure S1. Trajectories of water demand with varied shortage awareness weight factors.

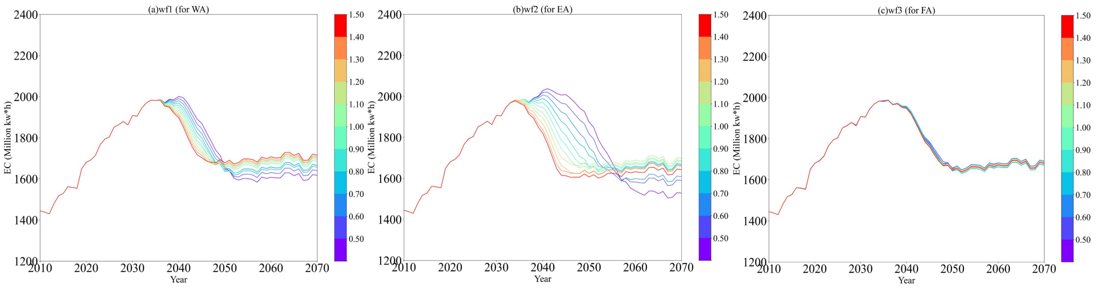


Figure S2. Trajectories of energy consumption with varied shortage awareness weight factors.

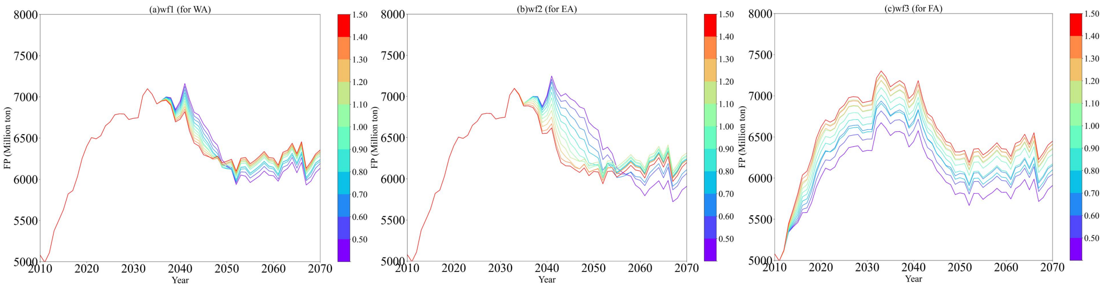


Figure S3. Trajectories of food production with varied shortage awareness weight factors.

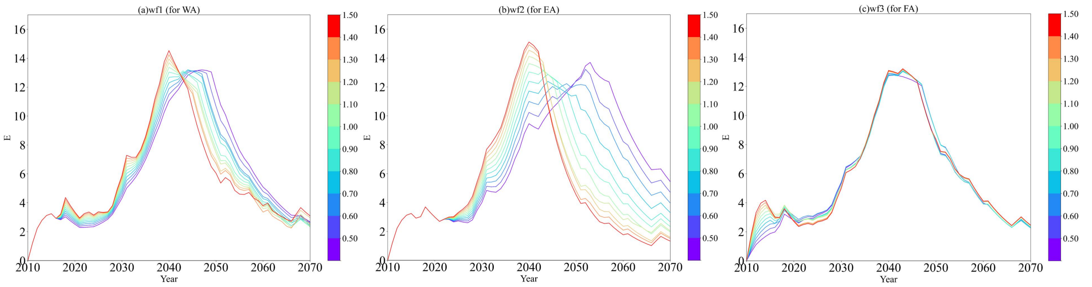


Figure S4. Trajectories of environmental awareness with varied shortage awareness weight factors.

WEFS nexus is sensitive to shortage awareness weight factors. Specifically, weight factors for water and energy shortage awareness can remarkably impact the recession phases of water demand, energy consumption, and food production. Lower weight factor can delay environmental awareness accumulation, and thus extend the contraction phase. However, more violent socioeconomic deterioration was also accompanied in the later recession phase, which consequently led the slightly smaller socioeconomic size in recovery phase. Weight factor for food shortage awareness can effectively dominate the whole evolution of water demand, and energy consumption. Lower weight factor indicated that smaller food shortage awareness can be accumulated. Feedback to increase crop area was thereby weakened. Both agriculture water demand and food production were decreased. As energy use quota for agricultural water supply is negligible, little response of energy consumption can be found.

Second, we redefined the energy consumption in the first round of response according to your first review comments. We focused on the energy consumption during the water supply process for socioeconomic water users to further investigate the energy co-benefits of water resources allocation schemes. Simultaneously, boundary conditions for energy system was also updated (e.g., planning energy availability, energy use quotas). Results indicated the phase dividing rule was still valid for the nexus co-evolution, despite the amount of energy consumption was indeed decreased significantly. However, environmental awareness feedback on socioeconomic factors was determined by shortage rate, rather than the amount of shortage. As there were small differences in energy shortage rate evolution process with redefined energy consumption, former discussion on the impacts of energy system on WEFS nexus was still valid.

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