Interactive comment on "One-way coupling of an integrated assessment model and a water resources model: evaluation and implications of future changes over the US Midwest" by N. Voisin et al.
Editor

Dear editor,

Thank you for the feedback and suggestions to further improve the paper.

We have further revised the manuscript to clarify the purpose and significance of the study. Our ultimate goal is to develop a fully coupled earth system model in which human systems and natural systems are interactive across a wide range of scales. As a first step towards that goal, this study demonstrates one-way coupling of an integrated assessment model that simulates water demand and a water resources modeling system that integrates a land surface model, a river routing model, and a reservoir operation model. Although climate scenarios are prescribed based on statistically downscaled scenarios, this study differs from many previous impacts studies in that socio-economic and energy policy are modeled (by the integrated assessment model) and explicitly considered in the water management through changes in water demand. Previous studies typically investigated only changes in natural streamflow driven by climate change, with or without water management, while water demand is fixed. Hence we consider a broader set of human-earth system interactions than typically included in previous studies. This allows us to investigate the relative influence of demand changes vs natural flow changes on water supply deficit in the future.

Therefore, in addition to the planned revisions described in our previous response, we added the following:

1) More discussion on the water demand projections and how they are driven by socio-economic factors. This distinguishes our research from previous studies that mostly ignored changes in water demand. We added:

> *"The steady increase in irrigation water withdrawal (Figures 5) in the Midwest is primarily attributed to the projected expansion of biomass especially in the second half of the 21st century. One the other hand, the projected reduction in total non-irrigation water withdrawal is mainly attributed to the technological change of water cooling technologies for electricity generation (Figures 5); i.e., the phasing out of once-through cooling technology and the greater prevalence of more water efficient cooling technologies such as recirculating towers and cooling ponds. Although the total water withdrawal results also encompass the effects of population growth, income effect, fuel mix, energy demand, and climate mitigation, the effects of cooling technology dominated the direction of the change. Since recirculating technologies generally withdraw much less but consume more water than once-through cooling, the total consumptive use for non-irrigation, unlike withdrawals, shows a slight increase."*

2) We also went deeper on the explanation for why changes in the regulated flows and supply deficit are more driven by changes in natural flow rather than demand overall but varies regionally. Covariances between the supply deficit and the inflow and demand quantify over multiple periods the driver of changes. The elasticities generalize the findings by quantifying the sensitivity of regulated flow and supply deficit to changes in flow and demand. The combination emphasizes the complex interactions between the regulated flow and supply deficit, with the changes in demand and flow, the spatial distribution of the demand and the region's storage capacity. These again highlight new insights that can only gained with our one-way coupled integrated assessment and water resources models.

We added in the manuscript:

i) a table for the covariances of the supply deficit with flow and demand:

Table 4: covariances of supply deficit with inflow and water demand. Bold values are significant at the 90% confidence level.

	Missouri		Upper Mississippi		Ohio	
B1	Demand	inflow	demand	inflow	demand	inflow
2015-2095	**18%**	**37%**	6%	**32%**	7%	8%
2030s	3%	**55%**	13%	26%	15%	1%
2050s	24%	**37%**	0%	**41%**	0%	6%
2080s	0%	**61%**	6%	**41%**	0%	22%
A2						
2015-2095	**40%**	**17%**	15%	**21%**	**25%**	1%
2030s	26%	**28%**	10%	**50%**	7%	3%
2050s	3%	**32%**	6%	**50%**	4%	1%
2080s	25%	7%	19%	5%	2%	3%

In the results section, the relative change in regulated flow and supply deficit are first presented, as before. The covariances complement the original analysis by identifying the drivers of change. Elasticities quantify the sensivitivies of regulated flow and supply deficit to changes in flow and demand for the different periods and scenarios.

ii) we augmented the discussion section on the drivers of change by the following paragraph:

"We investigate the drivers of the change in regulated flow and supply deficit using covariances (Table 4) and elasticities (Table 3) with respect to climate-induced change in flow and changes in water demand driven by socioeconomic factors, energy and food demands, global markets and prices. "

[…]

"Because of the limited storage capacity of the reservoirs over the Ohio River, a relatively low demand, and cities with high demand but too far from the main stem to access the water supply according to our database rules, climate change effects on the natural flow drive the change in regulated flow (Figure 9) with changes being of about equal magnitude (elasticities close to 1). Changes in supply deficit are driven by changes in demand regionally but are driven by a combination of changes in runoff and demand locally around the high demand urban areas. For B1, the elasticity of the supply deficit with respect to changes in demand stagnates around 3. Relative to changes in flow, the elasticity is more uncertain with a higher range of fluctuation between 5.4 and 28.9. However, supply deficit over the Ohio is the least sensitive to changes in flow and demand than the other regions (Figure 12 and Table 4)"

[…]

(Over the Upper Mississippi,) "Changes in regulated flow are driven by changes in natural flow with elasticities close to 1 (Table 3), due to the limited storage capacity, relatively low demand with respect to the annual flow and cities and fields too far from the main stem, like over the Ohio. Elasticities with respect to changes in demand are small (between 0.05 and 0.41). The increases in supply deficit are driven primarily by the change in runoff as seen in Figure 12 and Table 4. Elasticities with respect to flow however are more uncertain as they range between 5 and 60 while elasticities with respect to demand stagnate between 2 and 3. "

[…]

"The supply deficit over the Missouri is controlled mostly by the natural flow over shorter periods and demand over longer periods. The Missouri is the most sensitive to changes in runoff and demand, showing the largest elasticities with respect to both flow and demand. The change in runoff is still the predominant driver of the change in supply deficit, especially under A2 when the system seems to reach its supplying limit. However sensitivity of supply deficit to changes in demand should be taken into consideration for climate change impact assessment given that about 21% of the annual flow is consumed.

For the Midwest, it is important to note that supply deficit is around six times as sensitive to changes in runoff and demand, than the actual supply; it increases to 10 times over the Missouri and decreases to 3 times over the Ohio and Upper Mississippi is. This emphasizes the predicted competition between water uses in the future and the importance to look at the water demand driven by socio- economics factors and global markets. It is also noteworthy to look at the range of elasticities of the supply deficit with respect to flow and demand over future periods and between a pessimistic A2 scenario and an optimistic B1 scenario, in particular from 2050s to 2080s when the A2 and B1 climate scenarios tend to significantly diverge. The range of elasticities show the complex interactions between changes in climate-induced natural flow, socio-economics changes in water demand, the storage capacity of the region and the reservoir model regulation and extraction. "

Best regards,

Nathalie