Referee comment on "The question of Sudan: a hydroeconomic optimization model for the Sudanese Nile"

Summary

The paper presents a hydro-economic optimization analysis of water allocation in Sudan, balancing water for irrigation and hydropower-generation purposes. It is generally well-written and demonstrates a firm understanding of the intricacies of Nile Basin hydrology. Though the modeling is not particularly novel, the questions asked will be of interest to readers of this journal. Some rethinking of the modeling is however required, as described below. In the absence of such revisions, it is difficult to really have much confidence in the results and conclusions drawn by the authors.

General comments

I wish to offer the following general comments:

1. The first major shortcoming of the paper is to ignore the role of changes in infrastructure and agricultural practices that could be independent of, or resulting from, changes in climate and upstream infrastructure development. As the authors likely know, there are several proposals on the table in Sudan for new infrastructure projects, and agricultural expansion (particularly in sugar production) is a major objective of current irrigation development strategy in Sudan. In addition, reservoir operating rules and irrigators are not likely to take climate change "fully on the chin"; i.e., they will adapt by changing management.

2. The second major shortcoming of the paper is the fact that it ignores the White Nile and the Atbara rivers completely. The problem with these omissions is that the water management situation in those rivers is dynamic and not insignificant (contrary to what the authors assert). In the White Nile, there are a range of changes underway between Gebel el Aulia and Khartoum, as well as long-standing plans related to the Sudd, a discussion that includes South Sudan. And changes in the Atbara and White Nile could both affect the negotiation of allocations under climate change. The paper must either be given a new title or the model expanded; at the moment it does not apply to the entire "Sudanese Nile."

3. The third issue is the treatment of the effect of upstream infrastructure. The authors do not provide sufficient justification for their temporal smoothing assumption, which is surprisingly ad-hoc given that they would appear to be able to model a new large dam in Ethiopia. Why not simply include such a project, optimized from Ethiopia's perspective? The other advantage of this is that it would allow for more realistic representation of the energy system, since a likely target for Ethiopian hydropower would be the Sudanese market. Because of the way the analysis has been structured, the model may overstate the tradeoff between hydropower and irrigation because it assumes no hydropower from Ethiopia will go to Sudan (this is acknowledged on p.11585 but the solution is again ad-hoc). I would urge a rethinking of the analysis along these lines.

4. The description of previous work in the Nile basin covers the existing hydro-economic optimization models well, but says little about important simulation work that has been used specifically to consider climate change implications, which seems very relevant. See Jeuland

(2010) in Water Resources Research and Jeuland & Whittington (2014). Note that the supplementary materials for the latter also include updated water demands for Sudan, compared to those used in the paper.

5. Model: I question the choice of valuing the irrigation benefits using agricultural profit margins (in the objective function). The problem is that this assumes that all profits are attributable to irrigation, which may not be the case. What the authors need instead is a marginal product of water in irrigation. Given this approach, I find it hard to interpret the tradeoff curves, which do not reflect the marginal contribution of water to agriculture profits.

6. A final (and difficult) issue I would raise is that the valuation must clearly be presented as a country-specific one. Despite the legal regime, Egypt has been releasing more than 55.5 bcm per year from the High Aswan Dam, because Sudan has not used her full allocation. This means that the true economic benefits of Sudan consuming more water thus must include the reduced water available in Egypt, where it is being used productively. If the paper is really about optimal economic use of water, it must explain and handle this issue clearly.

Specific comments

1. In the introduction p. 11567, the relevance of changing silt loads is not properly explained (lines 25-26).

2. I would advise the authors to update somewhat their data sources. In the introduction, based on a now dated study by Blackmore and Whittington, it is said that Sudan consumes 13.5 bcm/yr of water, which is likely on the low side, and does not include evaporation losses from the reservoirs behind the heightened Roseires Dam and the Merowe Dam, the latter of which should be included in Sudan's 18.5 bcm/yr allocation (e.g., the 10 bcm in the 1959 agreement is evaporation from behind Lake Nasser). Also, how evaporation from Roseires should be handled is ambiguous since the heightening was not written into the treaty.

3. Please review the equations section. Some terms (e.g. "Water") are not defined, and it is unclear how little "i" relates to big "I". I think the problem is that the water requirements of different crops have not been clearly explained.

4. Looking at constraint in equation 5, is it correct that the model allows Sudan to withdraw more or less than 18.5 in a given year so long as the total balances out? That seems problematic since Sudan would likely be tempted to take more water in drought years and Egypt would clearly not allow this. The oher reason that this formulation is problematic is because the discounting will necessarily front-load demands.

5. Model II: Random bootstrapping of flows will not maintain the autocorrelation in the hydrological time series. The authors should comment on the implications of this and whether it is likely to be an important shortcoming.

Technical corrections

1. P.11567, line 27: "analytical tools" not "analysis tools".
2. P.11568, line 5: "For the purposes of…"

3. Gezira – as in the irrigation scheme, is misspelled in different ways in different places (as Gezeira, Gezeria, etc.)
4. P.11575. line 16: The model does not maximize I. The objective function includes both agricultural profits and hydropower.