Responses to Reviewer 2
We thank the reviewer for their thoughtful comments on our paper. A detailed response to reviews is offered below.

Major Comment 1
*My main concern is with the hydro-economic model and, more specifically, with the method used to assess the contribution of irrigated agriculture to the system-wide benefits. Due to data limitations, the authors assume that the net benefits correspond to (crop price * production*AGM). This formulation overestimates the value of water as the contribution of the other inputs (fertilizer, land, etc) to the production of the agricultural goods is ignored. For the energy sector, the net benefits are given by price*hydropower where hydropower is a function of the head and the turbined outflow, which properly reflects the contribution of water. For a study emphasizing the economically efficient allocation of water, it is key that the marginal value of water in both sectors be treated on the same footing*

We acknowledge that our application of AGM was poorly framed. To address this shortcoming we have replaced AGM with a marginal value of agricultural water, an approach that has been used in previous studies (e.g., Whittington 2004, Whittington et al. 2005, Arjoon et al. 2014). Noting that agricultural data from the region is extremely limited, these authors used a flat demand curve with a constant marginal value of water at 0.05$/m^3 for all agricultural areas.

For this paper we have followed the approach of using a flat demand curve, but we have applied crop-specific marginal water values and performed a sensitivity analysis on the parameter. Six different combinations of marginal water value were tested, as listed in the table below. The ratio of the marginal values for each crop was calculated based on the producer price (P, $/ton), yield (Y, ton/m^2) and water content (W, m^3/m^2).
PY/W will give the $/m3 for each crop, thus a ratio of marginal value of water for each crop. Varying the values based on this ratio gives the table below. Sources: P (FAOSTAT website), Y(Ghezae, 1998 taken from a Rahad Research Station for potential yield values), W (Plasquelle 1990, takes into account initial irrigation and penman evap from Wad Medina)

	Marginal value of water ($/m3)					
	P1	P2	P3	P4	P5	P6
Cotton	0.287	0.118	0.036	0.008	0.001	0.00001
Wheat	0.062	0.025	0.008	0.002	0.000	0.000
Groundnut	0.083	0.034	0.011	0.002	0.000	0.000
Sorghum	0.017	0.007	0.002	0.000	0.000	0.000

Additionally, we would like to clarify that the marginal values presented here as well as the power pricing of 8 cents/KWh are chosen for illustrative purposes only. They are intended to assess the sensitivities of the model and are **<u>not</u>** meant to reflect an optimal estimate of current agricultural or energy market prices. This will be added in section 2.2 of the manuscript.

Major Comment 2

This study considers that all irrigation schemes in Sudan are supplied by the Blue Nile, which is not correct. There are schemes on the White Nile and the Atbara. So, the upper bound on maximum irrigation withdrawals must be corrected (eq 5).

Major Comment 3

In the '59 agreement, Sudan is entitled with 18,5 BCM/year, which includes both irrigation withdrawals and evaporation losses from reservoirs. So, eq. 5 must be changed accordingly.

Response to Reviewer 2 Major comments 2 and 3:

These comments both address important details of the 1959 treaty constraint. As the reviewer correctly points out, our constraint in equation 5 should be adjusted downward to account for other rivers and for reservoir loss. To account for both of these factors we have reduced the bound on maximum irrigation from 18.5 to 14.5—i.e., that approximately 80% of Sudan's total allocation will be used for irrigation in the Blue Nile plus the main stem Nile. This approximation is based on the relative contribution of Blue Nile flows to the Nile system and the recognition that the largest irrigation schemes in the country are located in the Blue Nile basin.

Thus we re-wrote the allocation constraint to:

$$\sum_{l,m,y} (i_{l,m,y}) + \sum_{l,m,y} (e_{l,m,y}) \leq \ Y * 14.5 \ bcm$$

The 14.5 approximation is generous, considering estimated reservoir evaporation losses and the potential for new irrigation schemes on other rivers, but we consider it to be a reasonable value that allows us to explore the full potential development space for the Blue Nile under the constraint of the 1959 treaty.

Please also see our response to Reviewer 1, specific comment 4, which also addresses the issue of the 1959 treaty.

Major Comment 4

The optimization model (1)-(8) is deterministic. The authors therefore assume perfect foresight over a period of 20 years. They should discuss the impact of this assumption on the results.

Response:
The deterministic nature of SHOM does not represent the uncertainties in some of the input parameters. Furthermore, a deterministic model allows for perfect foresight within the 20-year run period. Thus the results of the various models show the potential of benefits due to changing sensitivities under current Sudanese infrastructure. These decisions made in the presented scenarios are highly idealized and would produce results that are more efficient than any real world scenario.

For example, perfect foresight allows for pre-regulation of reservoirs to account for upcoming droughts well beyond the time horizon of existing forecast systems. The relevance of this kind of foresight to economic optimization is the subject of our ongoing research, which aims to understand the value of predictions to hydroeconomic outcomes in the Nile. We now note the prefect prediction issue and discuss its impacts on results in Section 4.

Major Comment 5

5-1:
Equation 2. This is supposed to be the hydropower production function. A close examination reveals that the units on the right-hand side do not correspond to energy (KWh). As a matter of fact, with rhe =(m3) ("amount of water passing..."page 11574, line 25), h = (m) and effh = (-), the product gives (m4) not (kWh). In the appendix, "rhe" has become a flow (eq. A4) not a volume. Please clarify. Also, what is the "efficiency of the dam" (effh)? I hope that this is not the efficiency of the power plant because the value of 0.5 would then be extremely low (and would favor the irrigation sector). Typical efficiencies for a hydropower station range between 0.8-0.9. it is suggested that the authors use the classic hydropower production function which depends on the head, the flow, the density of water, the efficiencies of the turbines and the alternators, the acceleration of gravity, etc. It can be found in any good textbook in water resources engineering.

Response
Agreed. The equation presented in the paper excludes a conversion parameter. This parameter was present in the model.

Equation for hydropower:
Changed from

$$\forall_{l,m,y}, \ \ KWH_{l,m,y} = \frac{effh * rhe_{l,m,y} h_{l,m,y} (seconds\ per\ month)}{3600}$$

to: $\forall_{l,m,y}, \ \ KWH_{l,m,y} = 2.61e - 3 * n * effh * \ rhe_{l,m,y} * h_{l,m,y}$

rhe is the average hydropower release during month m, h is average height during month m, n is the number of seconds in month m, effh is efficiency and 2.61e-3 is a conversion factor. The equation above is derived from the hydropower equation (Cohon, 2003). This conversion factor is approximately the product of the acceleration due to gravity and the density of water, divided by 3600s * 1000 to give power generated in KWh..

5-2:

Crop yield (table 1). 1 ton/ha for wheat in an irrigated scheme seems very low. See recent Msc Thesis "Land and water productivity of cash and food crops in Gezira scheme" by Mohamed Osman, University of Gezira (2009) for more realistic yields in the region.

Response:
Thank you for bringing "Land and water productivity of cash and food crops in Gezira scheme" by Mohamed Osman, University of Gezira (2009), to my attention. Unfortunately, I have not been able to find Osman's thesis. I was able to find a published paper by Elmulthum of Gezira University "Food and water security in the Arab world and Sudan: Status and Threats" Resources and Environment 2012, 2(6): 265-270. This paper utilizes Osman's data and concludes:
NB: [16] is referencing Osman's thesis.

"*Applying data from[16] results obtained indicated that water productivity of food crops is very low in Sudan. Figure (7) shows that average water productivity of Sorghum, Wheat and Groundnut was estimated at 0.21 kg/m3 , 0.12kg/m3 and 0.17kg/m3 , respectively. These figures are very low compared to the average international water productivity of these crops which was estimated at 1.35 kg/m3*"

This is not the only paper that makes the case for low actual yields. All the raw data presented in alternative documents provides exceptionally low actual yield values. By my calculations 0.12kg/m3 with a water content for wheat at 0.589 m3/m2 gives a yield of 0.7 tons/ha, so an estimate of 1 ton/ha for actual yield is not unreasonable.

That said, there is a case to be made that an optimization analysis like this should use potential yield rather than actual yield. For this reason we have replaced the actual yield number with a potential yield value of 3.74 ton/ha, following values in [Ghezae N. (1998). Irrigation Water Management. A Performance Study of the Rahad Scheme in Sudan, 1977-1996. Thesis (PhD). Uppsala University Library. Uppsala, Sweden], which presents higher potential yield values derived from the Rahad research station. All results presented in the paper now use this formulation.

5-3:
An irrigation efficiency of 0.8 is way too high. This might be the official figure from the Sudanese government but studies have shown that this is grossly overestimated. See Msc Thesis "Irrigation performance of Gezira scheme in Sudan..." by Thiruvarud-chelvan, UNESCO-IHE (2010)

Response:
Thank you for noting the discrepancy between official and actual efficiency estimates. I was unable to find "Irrigation performance of Gezira scheme in Sudan..." by Thiruvarudchelvan, UNESCO-IHE (2010) MSc. However, I was able to derive the values of Technical efficiency (ratio of yields to total water used) from Elamin et al. "Water Use Efficiencies of Gezira, Rahad and New Halfa Irrigated Schemes under Sudan Dryland Condition" Sudan J. Des. Res. 3(1):62-72, 2011.

Technical Efficiency values for each crop in each scheme.

	Cotton	Sorghum	Groundnut	Wheat
Geziera	0.065	0.335	0.295	0.123
Rahad	0.065	0.345	0.25	0.475
New Halfa	0.065	0.32	0.39	0.1
Average	**0.065**	**0.333**	**0.312**	**0.233**

These values are now noted in Table 1 in the manuscript

5-4:
Crop price (Table 1). Are those the farmgate prices? What are the sources?

Response:
Crop Prices are the producer prices provided for each country for each crop in the FAO database. Source: http://faostat.fao.org/site/703/default.aspx#ancor.
We now cite this source in the text.
5-5:
Electricity price (Table 1). The authors should explain how the price of electricity is determined (and to what it corresponds). Please provide a reference.

Response:
Electricity price have been changed to 8 cents/KWh, this value was used in past studies by Whittington (2004, 2005), Block(2010) and Arjoon (2014).

Other Comments

P11567L22 change "though external influences..." to "through external influences..."

Response: Corrected

P11570L23 mentions "human infrastructure". Human infrastructure relates to things such as health, education, nutrition etc. This should read "infrastructure" only.

Response: Corrected

Some sentences are awkward and difficult to read. For example P11572L9-17 which *reads "The model produces distribution functions for dam geometry, evaporation loss and irrigation intended to inform dam management policies." is awkward. In Goor et al., the hydo-economic model does not produce distribution functions for dam geometry. Allocation decisions can be presented in the form of distribution functions. P11582L24-26 reads "Egypt might view movement to the right on the chart increasing irrigation withdrawals – as a potential threat to water resources in the ab- sence increased Nile river flow or counterbalancing shared benefits." This is difficult to understand and should read "Egypt might view movement to the right on the chart – increasing irrigation withdrawals – as a potential threat to water resources in the absence of increased Nile river flow or the counterbalancing of shared benefits."*

Response: Corrected

P11572L9 change "...economic benefits for all players more than double..." to "...economic benefits for all players more than doubled..."

Response: Corrected

P11573L16 change "whilst" to "while"

Response: Corrected

P11576L14 reads "The storage at each dam location must be equal to a simple water balance". This should be "The storage at each dam location can be calculated using a simple water balance."

Response: Corrected

You have used the words dam and reservoir interchangeably. They are not interchangeable. The dam is the barrier that creates the reservoir. For example, P11576L14-16 reads "The storage at a particular time step is the total water contained in the dam in the previous time step plus the water entering each dam minus what comes out of the dam through upstream flow." In this sentence the word dam should be replaced by the word reservoir.

Response: Corrected

P11570L5-6 reads "The dams also supply various schemes in Rahad Suki as well as upstream and downstream of Sennar...". This should be "The dams also supply various schemes in Rahad and Suki as well as..."

Response: Corrected

P11570L24-28 reads "They are particularly valued in complex water management *problems because they can inform a dynamic analysis of water resources and needs that guides basin managers...". The use of the word inform is incorrect in this sentence. This should read "They are particularly valued in complex water management problems because they provide a dynamic analysis..."*

Response: Corrected

P11572L19-20 reads "...calculates the economic benefit of development and changes to the climate to upstream portions of the Blue Nile." This should read "calculates the economic benefit of proposed development under changing climatic conditions."

Response: Corrected

When referring to another section of the paper use "See section N.NN" format. For example, P11570L21 reads "(see irrigation constraints)". This should be changed to "(See section 2.1.3 on irrigation constraints)". There are other instances like this. Please validate and change all instances.

Response: Corrected

In tables 1 and 2, please validate the units. Area = Area irrigated = m2/month ? Since, in the equations, the variables are all dependent on location (l), month (m) and year (y) it is then confusing, and unnecessary, in table 2 to define units as something per month.

Response: m2/month changed to m2

A comparison of presented results with those from other/similar studies should be included:

a) McCartney et al., Evaluating the downstream implications of planned water resoruce development in the Ethiopian portion of the Blue Nile River, Water International, 2012

b) Arjoon et al, Hydro-economic risk assessment in the eastern Nile River basin, Water Resources and Economics, 2014

Response: A comparison between Arjoon results and the findings of this paper are presented in Section 4 of the manuscript.

McCartney et al. (2012) is an intriguing paper that performs similar analysis but within a different region of the Nile. While we agree with McCarthy that issues of climate change adaptation, water resources management and development are inextricably connected, we feel that due to the lack of overlap in the study area a direct comparison with the actual results of the analysis cannot be made.

Please ensure that all statements that need to be referenced are referenced. For *example: P11585L9-11 reads "The GERD, for example, is expected to generate electricity that can be sold at about half the price of existing Sudanese facilities, and the dam will be connected to the Sudanese grid." This should be referenced.*

Response: An article issued on 7th December 2013 in Sudan Vision Daily reports "purchasing electricity from Ethiopia at 4 cents ".
http://news.sudanvisiondaily.com/details.html?rsnpid=229800
This article will be referenced in updated manuscript.

On P11570 in the paragraph in which the various dams in Sudan are described, the size and capacity of the dams are mentioned, except for Merowe (last 3 sentences in the paragraph). This information should be added

Response: A brief description of Merowe was added to section 1.1

On P11579-11580 it states "There is a significant connection between dry periods and hydropower release at Roseires. This is illustrated by a reduction in Hydropower release during the periods of dry annual flows (months 70-120 and months 190-240), and higher hydropower release during wet periods (Fig. 3c)." First, hydropower should not be capitalized. More importantly, in figure 3c we see a range of hydropower releases for the 3 dams. For Roseries, the high release is maximized at around 2500 million m3. There is a variation in the low release. I suspect that it is this variation in low release that is discussed in the sentence. In other words, "This is illustrated by lower hydropower releases during the periods of dry annual flows than during the wet flow periods."

Response: Corrected

On P11575L19 it states "...dependent on the water content for each crop type, at a specific month in a particular year." Water content should be changed to water requirement.

Response: Corrected