Nile Basin Initiative

Eastern Nile Technical Regional Office (ENTRO)

Nile Cooperation for Results (NCORE)

Climate Risk Assessment Study

Consultancy Service

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Report on

Planning Framework for Development under different Climate Scenarios

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1. Introduction & Background

The overall objective of the study is to develop and operationalize an analytical framework for integrating climate risks into the process of investment planning and management of the EN water resources. Such analytical framework for Climate Risk Assessment (CRA) could be used to guide water related investment in the EN and form the basis for climate screening for investment project and provide guidance to the development of climate smart strategies.
The specific objectives of the consultancy are:

(i) Customize the proposed Climate Risk Assessment (CRA) Methodology for the EN, with a set of Adaptation and Mitigation measures integrated as part of the show case to illustrate the effectiveness of the proposed methodology in promoting climate smart planning and climate resilient growth.

(ii) Address challenges facing the operationalization of the proposed framework, identify and prioritize future strategic directions for designing climate smart measures in the EN.

(iii) Strengthen the capacities of the EN national & regional institutions and their abilities to use the proposed analytical framework for climate risk assessment, as means for integrating adaptation and mitigation measures as part of the planning process.

(iv) Develop climate smart development strategies incorporating, interventions, impacts on indicators and prioritized options. This will be undertaken through assessment of current situation (information, institutions, infrastructure), identification of system sensitivity to historic conditions, establishing planning framework and carrying out capacity building and regional consultations at key stages of the study.

Here, in this report we describe a Planning Framework for Development under different Climate Scenarios

2.0 Scenarios for future climate conditions in the Eastern Nile basin:

In this section we review current state of knowledge about climate change in the Nile basin region and predicted changes in Nile flows. While nearly all studies agreed that temperatures will increase, rainfall predictions are less certain. Predictions of response by the Nile flow to the change in chemical composition of the global atmosphere vary widely; different studies give conflicting results. The summary of Yates (1998b) results shown in Figure 1 is an example of how widely results vary. The two numbers on ends of each line represent extreme discharges of six different GCM scenarios, whereas the boxed number is the historic long term average. Additional tick marks on each line are remaining GCM scenarios, which indicate range of climate change induced flows at different points in the Nile Basin. Five of the six GCMs showed increased flows at Aswan, with increases as much as 137%. (UKMO). Only one GCM showed a decline in annual discharge at Aswan (-15%). All numbers are in the units of cubic kilometers per year.

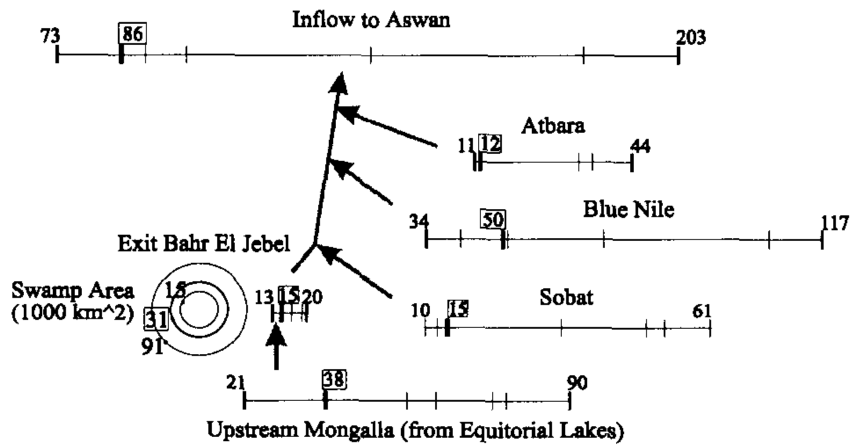

FIG. 9. Graphical Representation of Range of Discharges for Major Points along Nile (Two Numbers on Ends of Each Line Represent Extreme Discharges of Six GCM Scenarios, Whereas Boxed Number is Historic Average; Additional Tick Marks on Each Line are Remaining GCM Scenarios, which Indicate Range of Climate Change Induced Flows of Nile Basin)

Figure 1 – Range of discharges for major points along the Nile.
(Yates et al., 1998b)

To illustrate these differences further we review other similar studies. The predictions in Strzepek (1995) vary from 78% flow reduction in the GFDL simulation to a 30% increase in the GISS model. These results are confounded by Yates (1998a) predictions, which vary from 9% flow reduction for GFDL model to a 64% increase in the GISS model. Although most model results indicated that the Nile flow is quite sensitive to changes in precipitation. Hulme (1994) concludes Nile discharge will decline due to greater evaporation; specifically, he predicts reduced Blue Nile flows and constant or slightly increased White Nile flows. Similarly, Sene's (2001) results suggest a slight increase in White Nile flows. Conway (2005) concluded that analysis of climate change projections for the Nile basin region shows there is no clear indication of how Nile flows will be affected because of uncertainty about future rainfall patterns in the basin. In a recent study Elshamy et al. (2009) studied the impacts of climate change on Blue Nile flows using 17 bias-corrected GCM scenarios. They concluded that "There is no consensus among the GCMs on the direction of precipitation change. Changes in total annual precipitation range between −15% to +14% but more models report reductions (10) than those reporting increases (7)"

In the 1980s, a global body of climate scientists, the Intergovernmental Panel on Climate Change (IPCC), was formed to provide scientific advice to growing international political negotiations over how to respond to climatic change. In their 2001 report, the IPCC notes that because the Nile and other major rivers in Africa "originate within the tropics, where temperatures are high, evaporative losses also are high in comparison to rivers in temperate regions. Elevated temperatures will enhance evaporative losses; unless they are compensated by increased precipitation, runoff is likely to be further reduced" (IPCC, 2001a).

An IPCC report (4th Assessment) relevant to Africa was issued in 2007 (Boko et al, 2007). Figure 2 is based on the results presented in this recent report. It shows the range of predictions made by different GCMs for the surface temperature over Africa up to the year 2100. The different colors (red, orange, and blue) denote the different emissions scenarios. The blue set of predictions corresponds to the most optimistic scenario assuming significant action to mitigate climate change. The red set of predictions corresponds to "business as usual", or continuation of the current trends in emissions of greenhouse gases. The orange set assumes limited mitigation efforts. While these different assumptions result in slightly different magnitudes of the predicted warming over East Africa, all the models simulations and under different emissions assumptions agree in the prediction of a warmer future with annual temperature in 2100 rising by 4 degrees C (+ or – 1 degree C). It is also important to note that for current conditions the magnitude of the observed warming of order 1 degree C over East Africa is consistent with the models simulations.

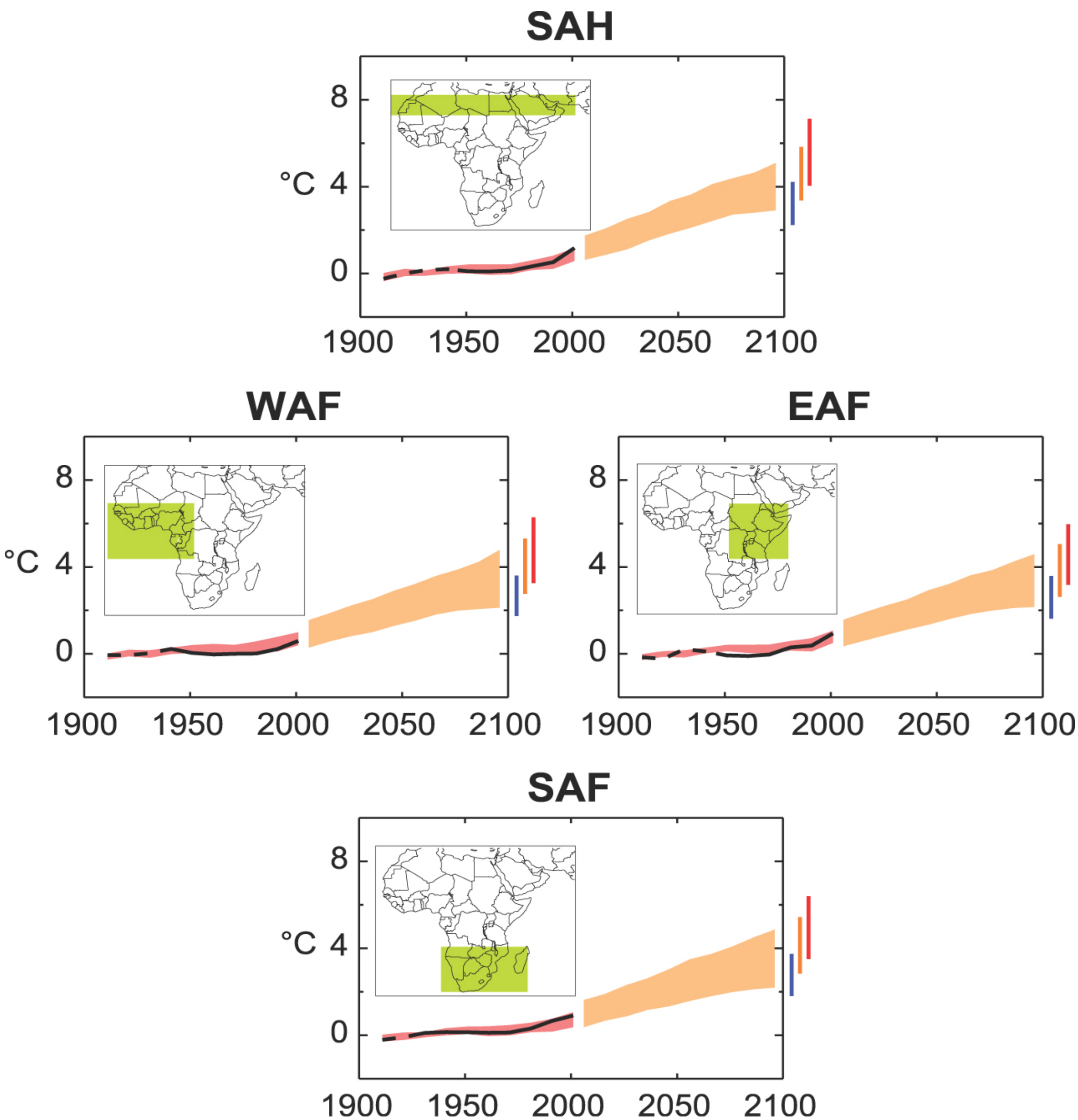

Figure 2: GCM predictions of surface temperature over African regions, (Boko et al, 2007).

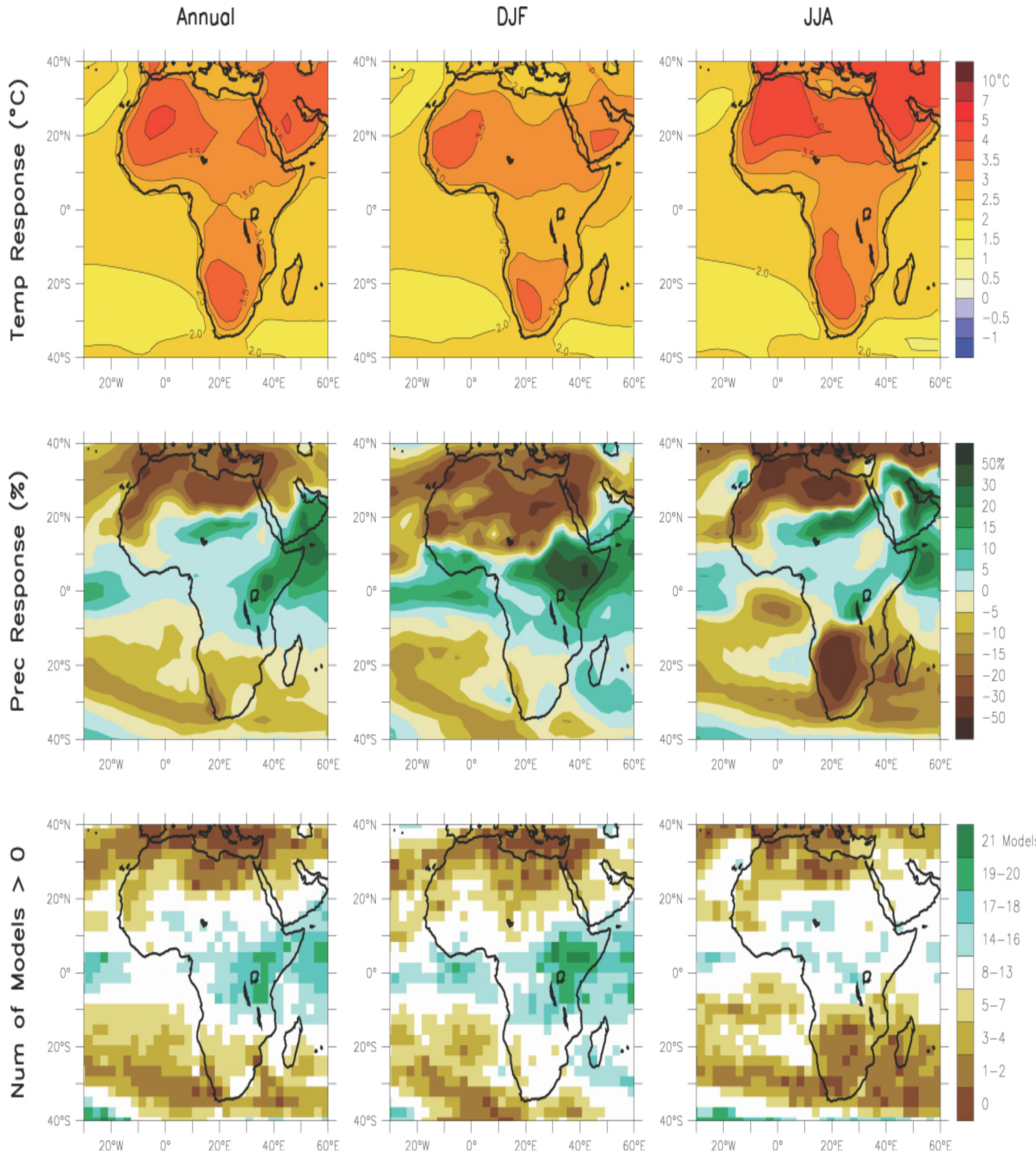

Figure 3: GCM predictions of surface temperature change (Temp Response); precipitation change (Prec Response (%); and number of models that predict an increase in precipitation (Number of Models >0). All results correspond to 2100. IPCC report (Boko et al, 2007).

Figure 3 shows the distribution of the predicted warming in surface temperature. The same figure shows the distribution of the predicted change in precipitation over Africa. Although, on average models seem to predict an increase in precipitation over the Nile basin, the results presented in the same figure indicate that about half of the models considered seem to predict an increase in precipitation while the other half predict a decrease in precipitation. This last conclusion is significant. It points to the high level of uncertainty about the sign of the predicted change in precipitation. While global models seem to agree in predicting warming of surface temperature over this region, the same models disagree on even the sign of the predicted changes in rainfall and river flow.

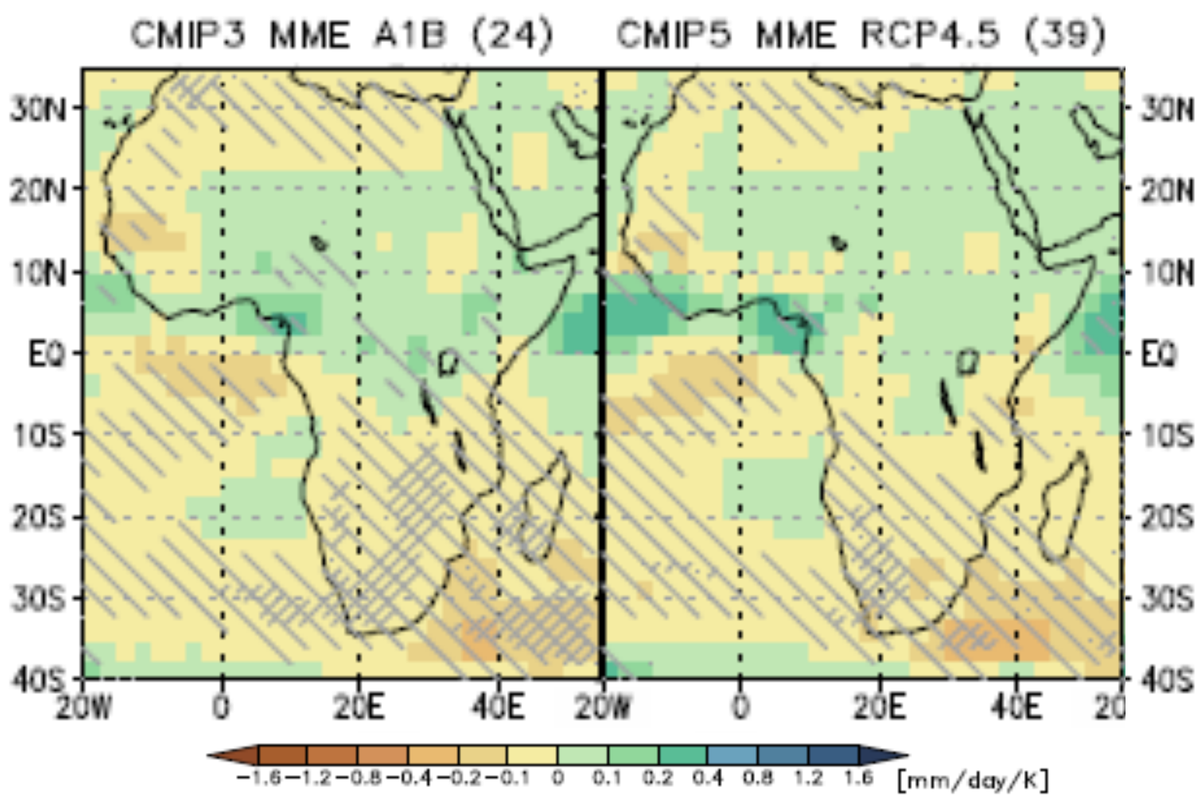

Figure 4: Predicted Change in Summer Rainfall (Hatched areas mark regions where models agree in the predicted sign of the change)

The most recent IPCC report (Fifth Assessment) was issued in 2013. The disagreement between the models still persists in CMIP5 (5th Assessment) as was the case in CMIP3 (4th Assessment). This is especially true for the differences between JJA rainfall over Nile basin, where half of the models show an increase and half of the models show a decrease. (Please see Figure 4)

Two climate change scenarios will be assumed. A wet scenario will consist of repeating the relatively wet decade of (1956-1965). A relatively dry scenario will consist of repeating the relatively dry decade of (1978-1987). We repeat the same analysis as we did for the historic sequence; assuming the standard configurations of the GERD, a smaller design and a larger design.

3.0 Performance for two configurations of the selected investment (Renaissance) assuming two scenarios of future climate conditions

We use two thresholds for any of the variables considered (selected indicators) to differentiate between: plenty, average, deficit conditions. These 3 states are defined, and estimated, such that the variable considered resides 1/3 of the time in each state. (Based on results of the questionnaire distributed in the stakeholder consultation workshop, see Appendix below)
After estimating these thresholds based on the historic run, then for each variable, we estimate the proportion of the time in these 3 states under climate change. In this fashion, we determine the increase (decrease) in the frequency of occurrence of conditions of (plenty, acceptable, deficiency) as a result of climate change. We explore the relative performance of the different indicators corresponding to different configurations of the selected investment under different operating rules and different climate change scenarios.

Climate Scenarios

As reviewed in previous sections, climate models disagree on the sign of the projected climate change impacts on the Nile rainfall and river flow. Hence instead of using predictions from any single model, we choose to use past decades of wet conditions, and dry conditions as proxy for likely changes in the climate of the Nile basin. For this Analysis two windows of climatic conditions were selected based on statistical analysis (5 years moving average) to represent dry and wet sequence of years. These are 1956-1965 for wet climate, and 1978-1987 for dry climate.

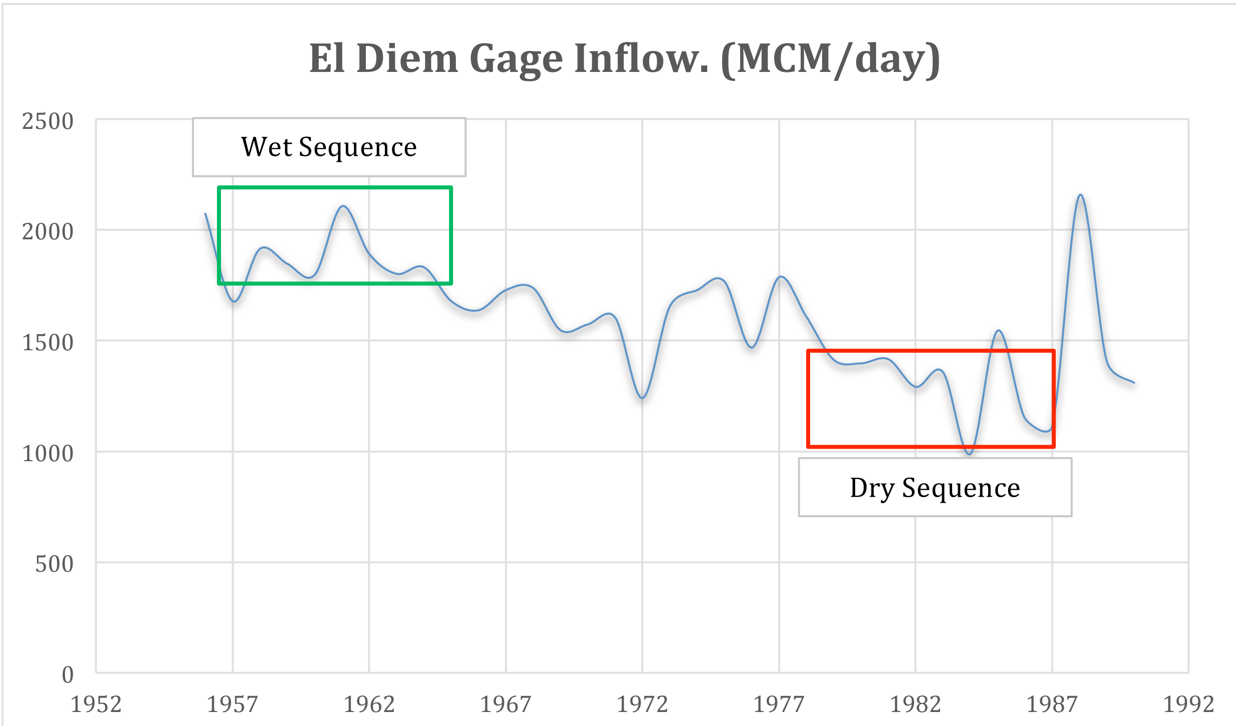

Figure 5: Wet and Dry Climate Change Scenarios for El-Diem Station in the Blue Nile

The wet and dry scenarios were separately constructed by repeating observed years of data for 35 consecutive years, i.e. 35 consecutive dry sequence of years and 35 consecutive wet sequence of years.

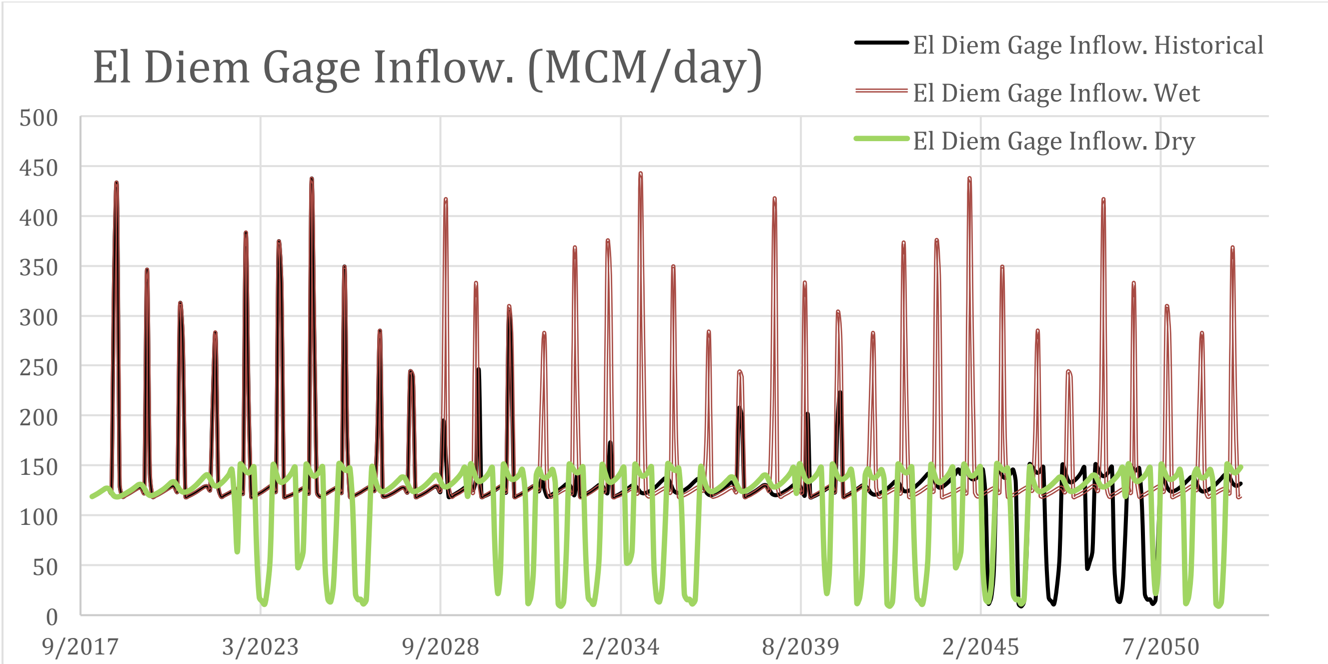

Figure 6: Historical, wet and dry scenarios at El-diem station

Using these two scenarios for 35 years, e.g. from 2017 to 2052, we can investigate the potential response of new and existing infrastructures to assumed climate change scenarios.

Infrastructure Scenarios:
Two infrastructure scenarios and two climate scenarios were considered in this analysis. The two infrastructure scenarios are two variants of the Great Ethiopian Renissance Dam (GERD). Two different heights have been considered for analysis: 135 and 115 m, or 620 masl and 640 masl for crest level. The three climate scenarios described above were assumed under these two infrastructure scenarios.

The RiverWare model was used in this analysis. RiverWare contains a flexible modelling environment that uses both an object-oriented workspace environment and rule-based policy language that allows a robust simulation of complex operational decisions and policies that govern the management of reservoir systems.

GERD is assumed to be at full supply level at the start of each simulation and hence filling is not considered.

Scenario 1: 640 masl for Renaissance Dam, crest level (135 m height)

(A) Power production at Renaissance dam:

For analysis purposes a threshold value of 33.3% or 1/3 probability of exceedance and 2/3 or 66.6 % probability of exceedance for the variable considered was selected. To do that the data will be ranked and the lowest 1/3 and the top 1/3 threshold values will be extracted from the historical series. Then the same thresholds will be used for determining the increase or decrease of the power production under the different climate change scenarios.

Since GERD is the most upstream reservoir considered in the analysis it's expected to be affected more by climate scenarios in comparison to the downstream reservoirs and water users. The system exhibit high sensitivity to the dry scenario, and relatively low sensitivity to the wet climate change scenario.

	Percent Exceedance	
Climate Scenarios	1,257,000 MWH/Month (Threshold Value)	1,299,000 MWH/Month (Threshold Value)
Historical	66.6 (2/3)	33.3 (1/3)
Wet	70	67
Dry	45	19

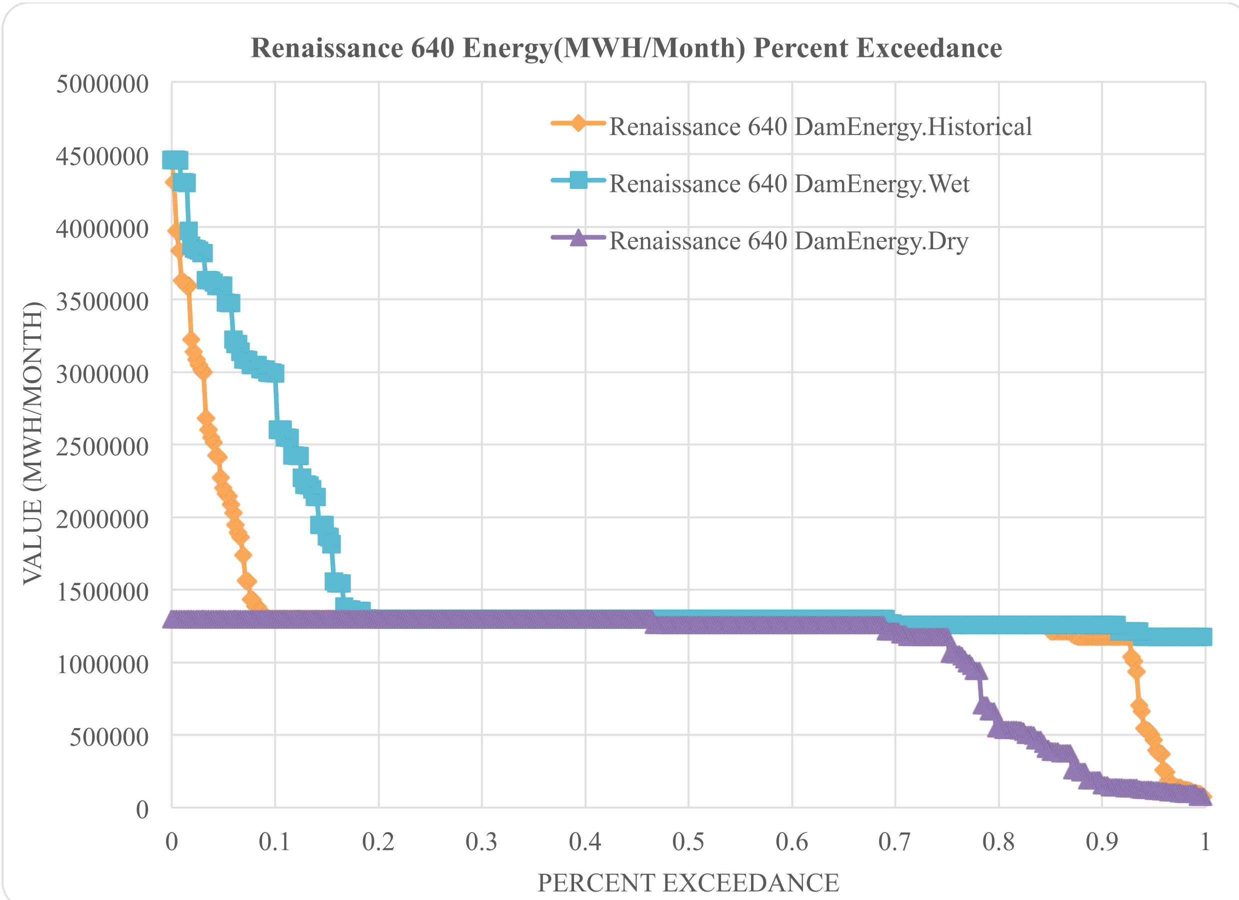

Figure 7 : Renaissance 640 Energy (MWH/Month) Percent Exceedance Scenario 1

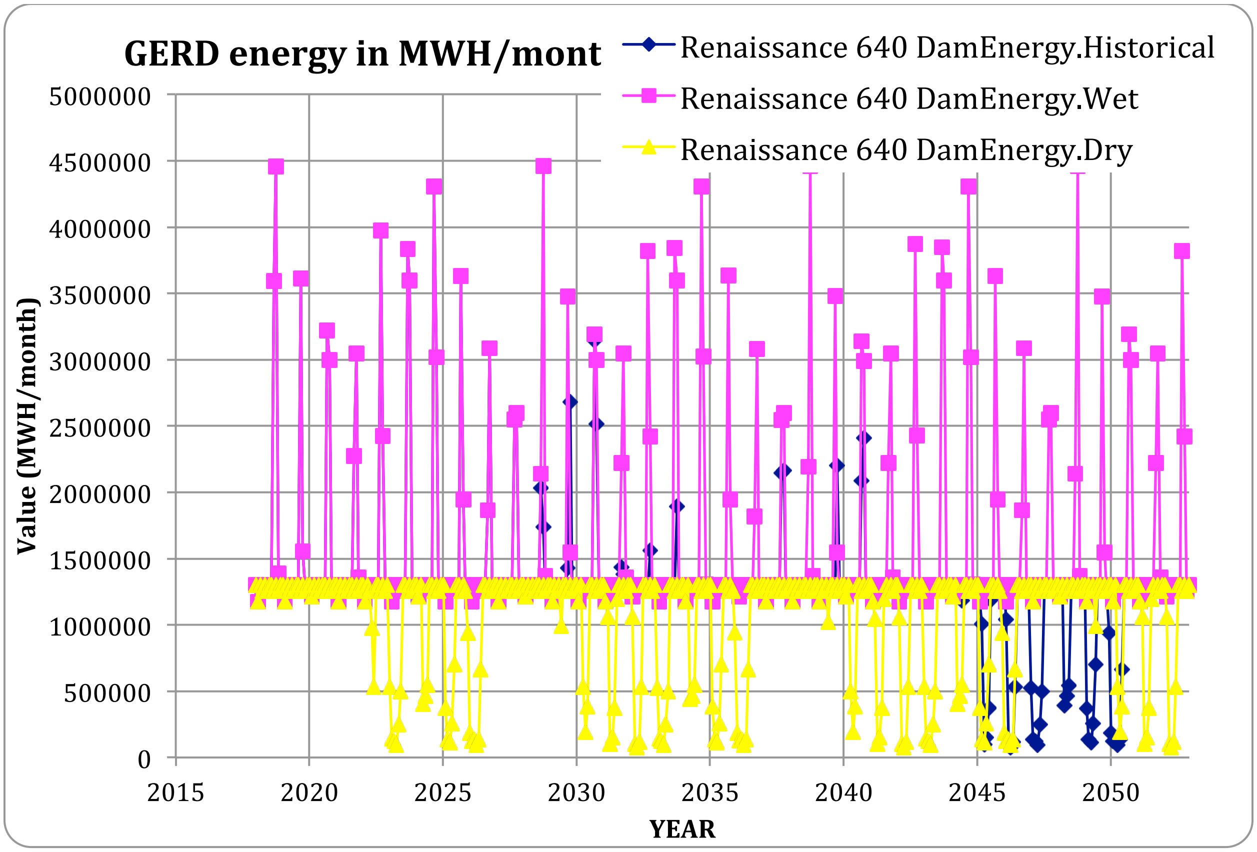

Figure 8: GERD energy in MWH/month Scenario 1

(B) Hydropower generation at Rosaries Dam:

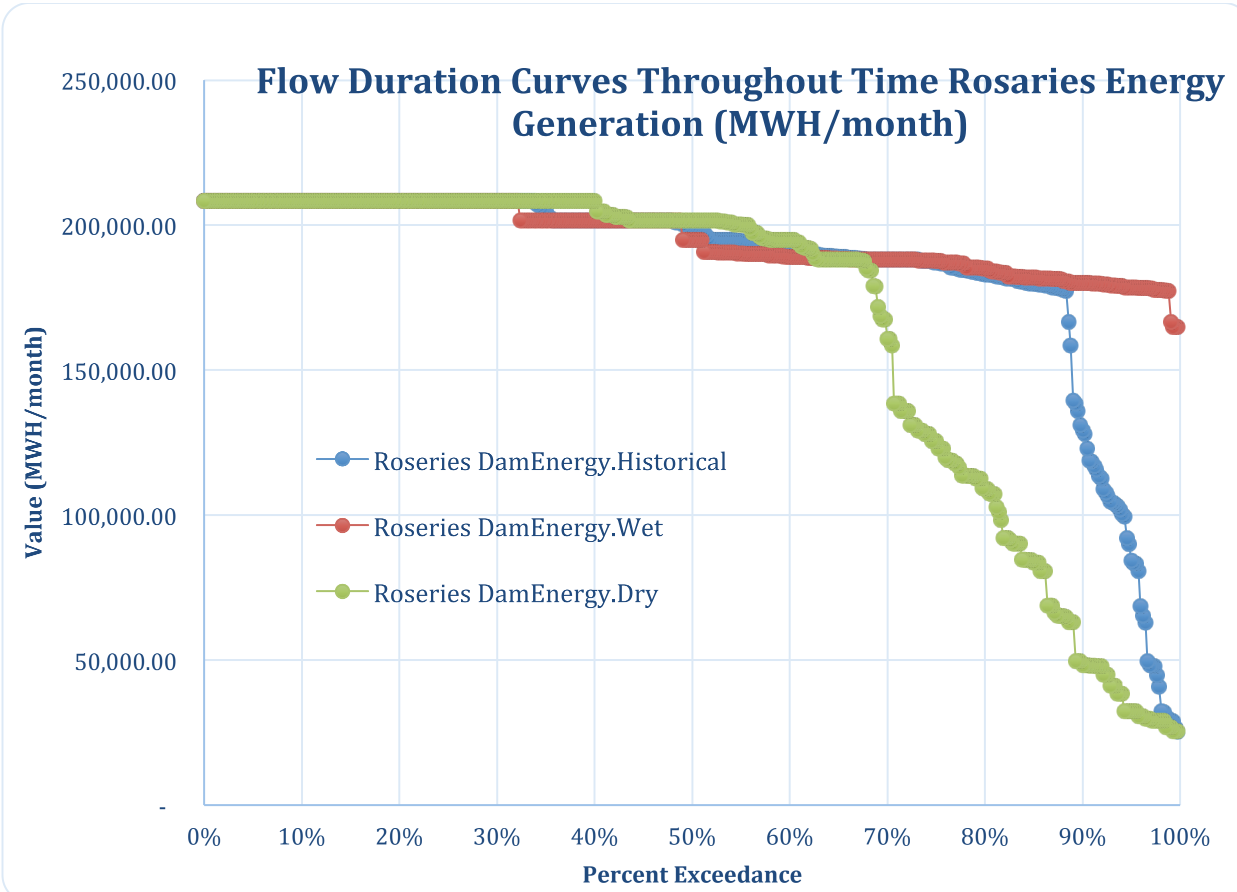

Figure 9: Flow Duration Curves throughout Time Rosaries Energy Generation (MWH/month)

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	Percent Exceedance	
Climate Scenarios	189,000 MWH (Threshold Value)	208,000 MWH (Threshold Value)
Historical	66.6 (2/3)	33.3 (1/3)
Wet	63.8	33.3
Dry	67	40

If you consider these thresholds under current and future climate change scenarios, there is no significant difference. This result indicates that hydropower in Rosaries is not highly sensitive, even improved in some cases, during dry periods at Rosaries dam. But when you look at higher reliability the picture is somewhat different.

	Percent Exceedance	
Climate Scenarios	84,000 MWH (Threshold Value)	129,000 MWH (Threshold Value)
Historical	95	90
Wet	100	100
Dry	84	73.6

This indicates power production up to 70 % reliability is not highly sensitive to climate change while the higher reliability is moderately sensitive.

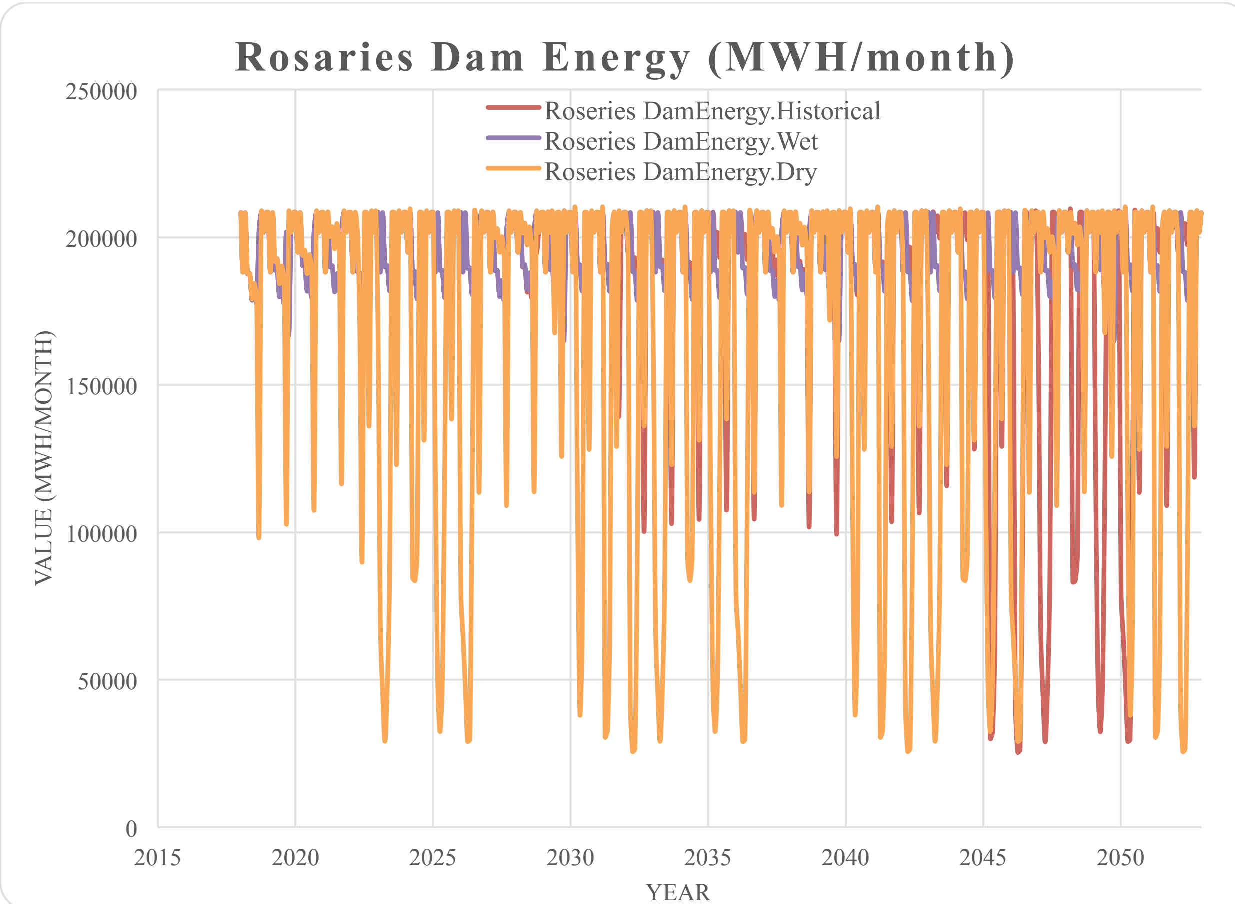

Figure 10: Rosaries Dam Energy (MWH/month) for Scenario 1

(C) Agriculture System in Sudan (irrigated):

The same approach of historical wet and dry climate scenarios is used for analyzing the response of the irrigation sector to climate change.

Figure 11 below indicates that the same amount of water use is simulated in all the three climatic conditions for irrigated agriculture in Sudan. This is a result of the regulated outflows from the GERD that acts as a buffer for downstream water users. Hence we can conclude that no significant impact is felt at downstream. Similarly, the two percent exceedance plots for Downstream Sennar and Gezira-Managil show no correlation with the climate change scenarios.

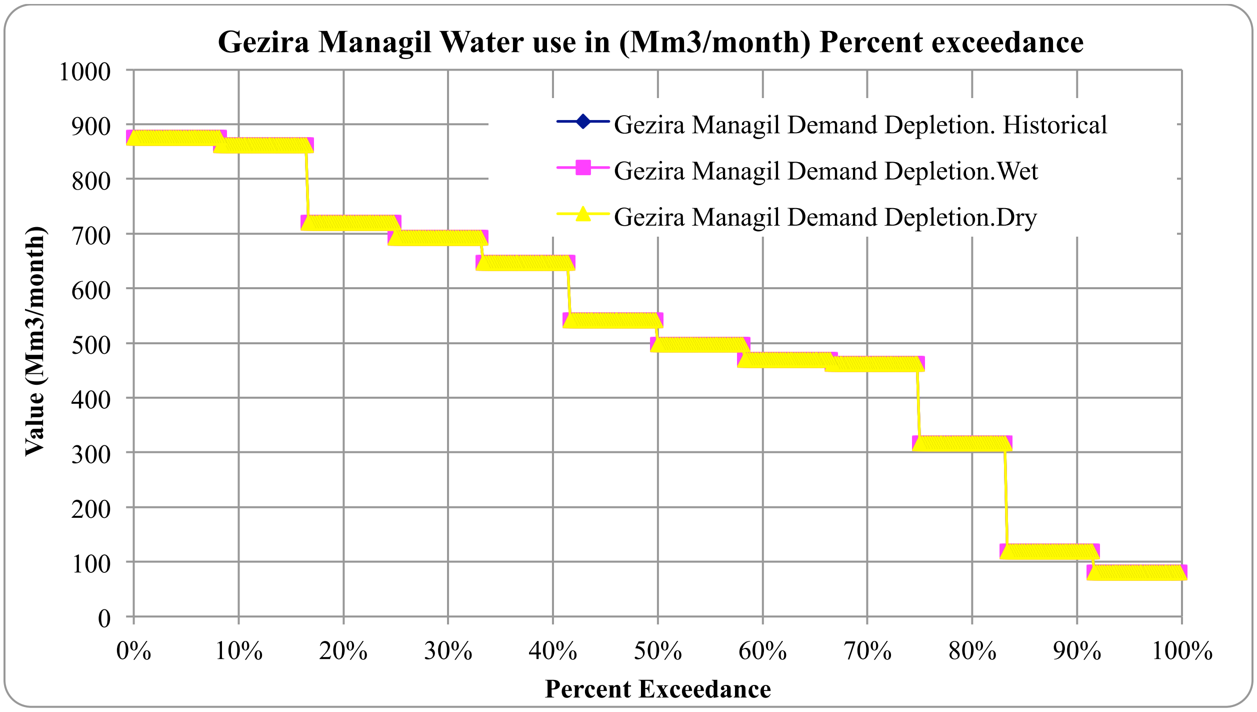

Figure 11: Gezira Managil Water use in (Mm3/month) Percent exceedance Scenario 1

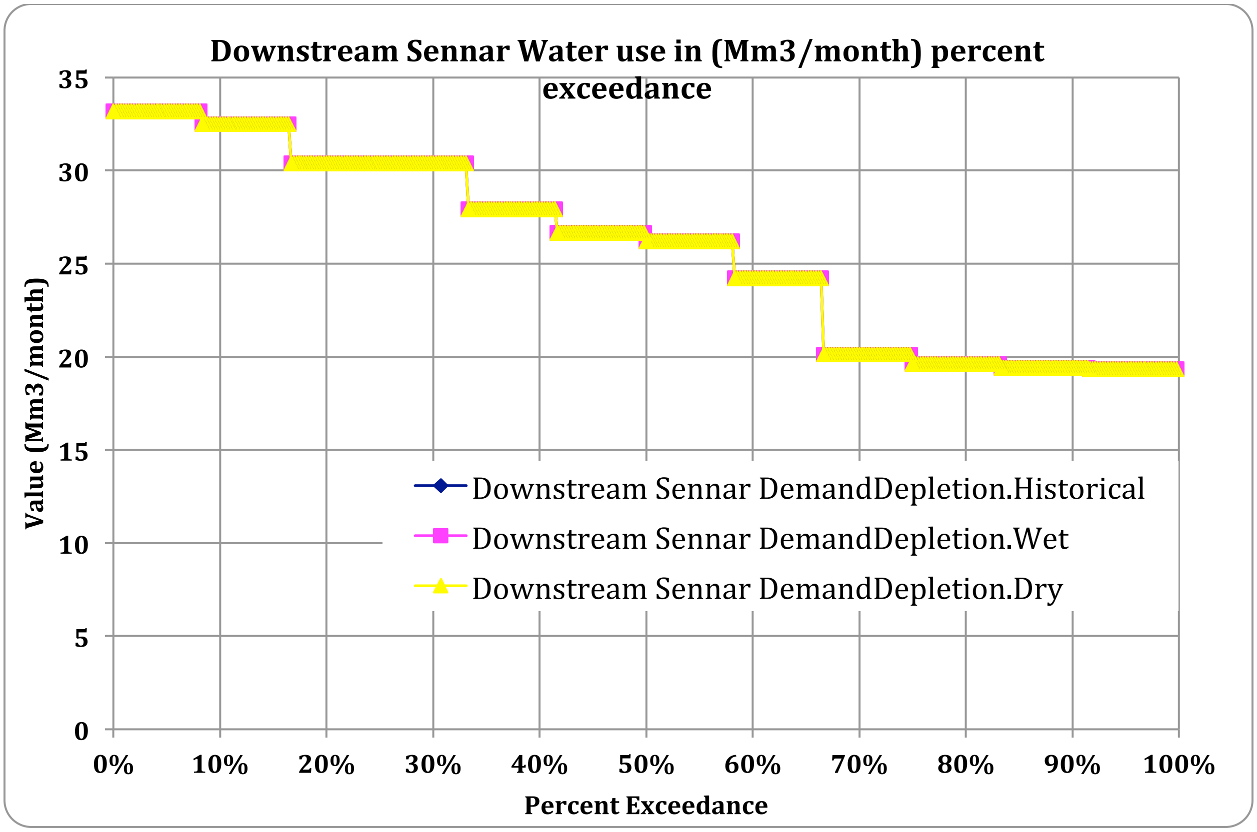

Figure 12: Downstream Sennar Water use in (Mm3/month) percent exceedance Scenario 1

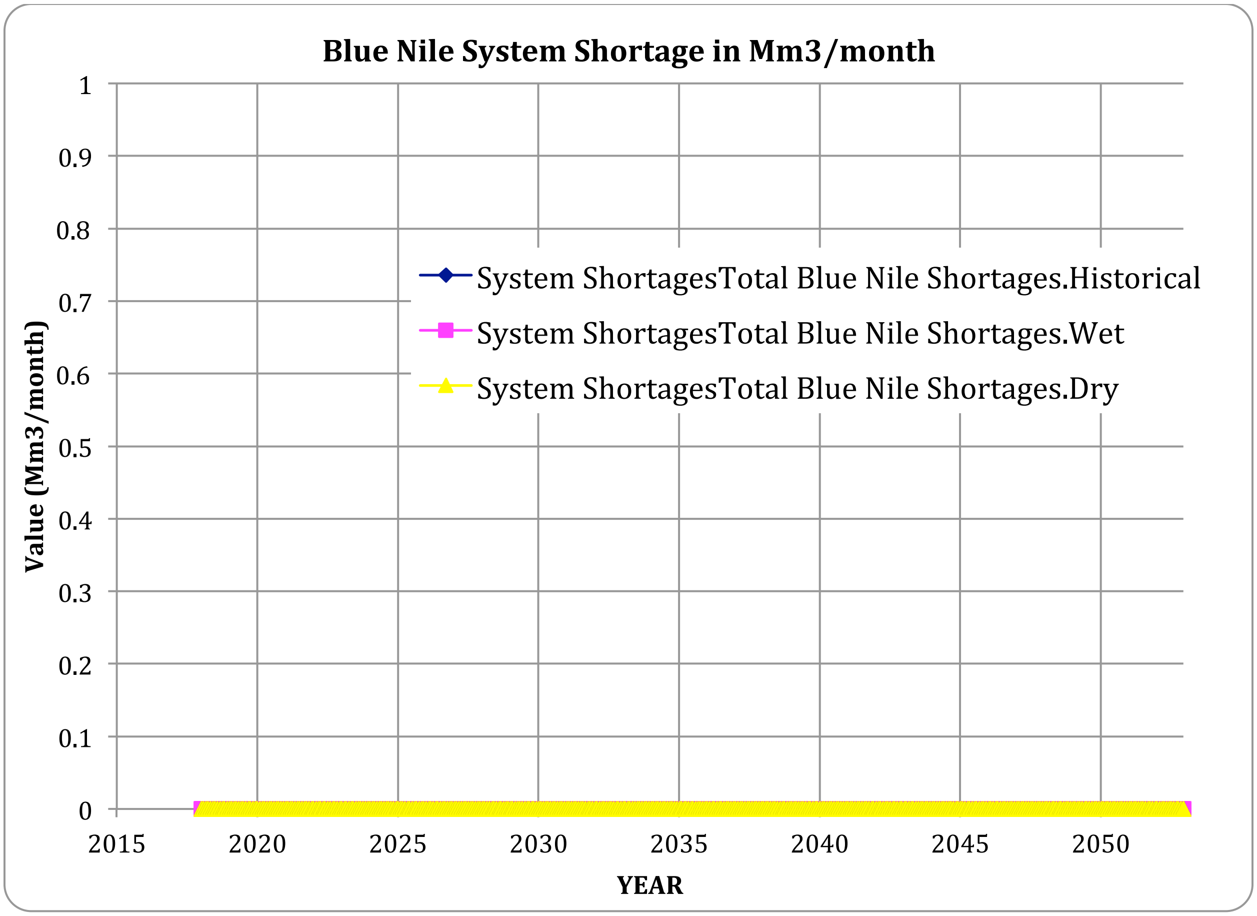

Figure 13: Blue Nile System Shortage in Mm3/month

There is no significant water shortage likely in the irrigated sector in Sudan.

(D) Water flow to Egypt:

Our initial assumption of full level at the GERD dictates that the High Aswan dam is not affected by filling of the GERD in this simulation, hence we can assume 173masl for initial water level behind the High Aswan dam.

	Percent Exceedance	
Climate Scenarios	4812 MCM/Month (Threshold Value)	5695 MCM/Month (Threshold Value)
Historical	66.6 (2/3)	33.3 (1/3)
Wet	66	35
Dry	49	19

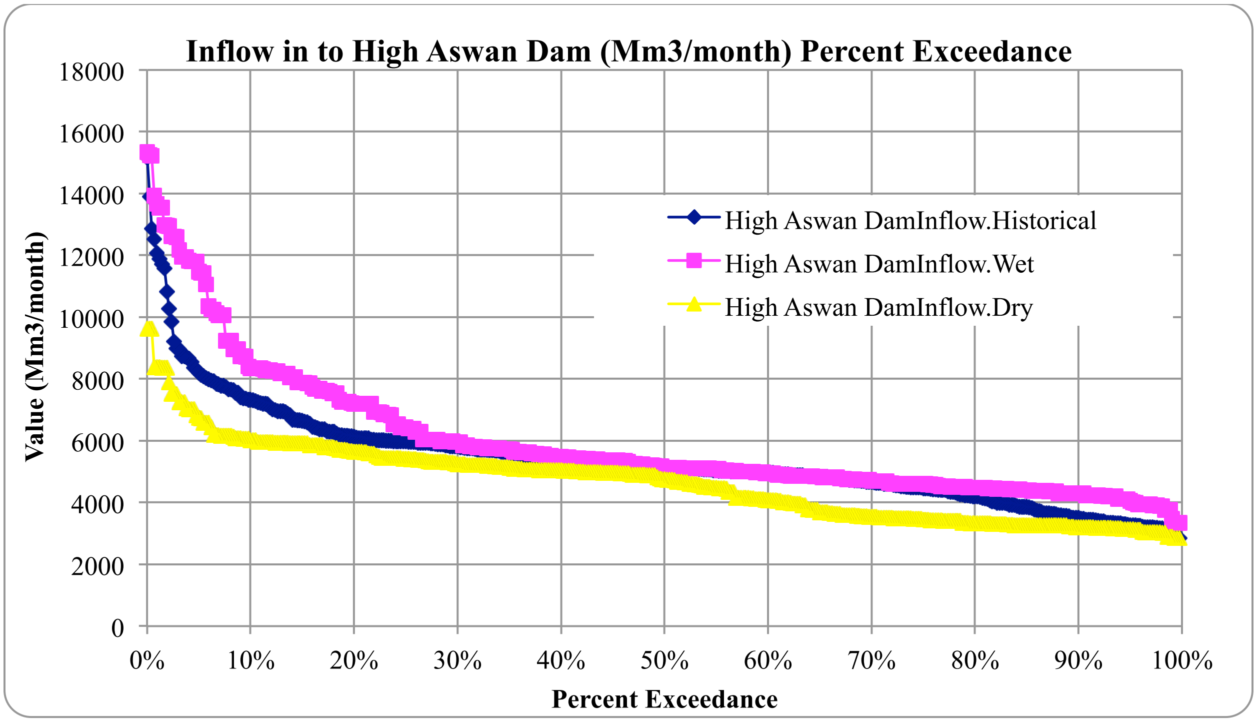

Figure 14: Inflow in to High Aswan Dam (Mm3/month) Scenario 1

Figures 13 and 14 suggest that the wet climate scenario would result in high inflow to the High Aswan Dam and dry climate scenario results in reduction of inflow to the dam. Note all the three graphs (scenarios) shown above assume 640 masl of dam crest level for GERD and also full supply level when simulation starts. Under the dry climate change scenario the flow of water to Egypt suffer significantly as evident in Figure 16.

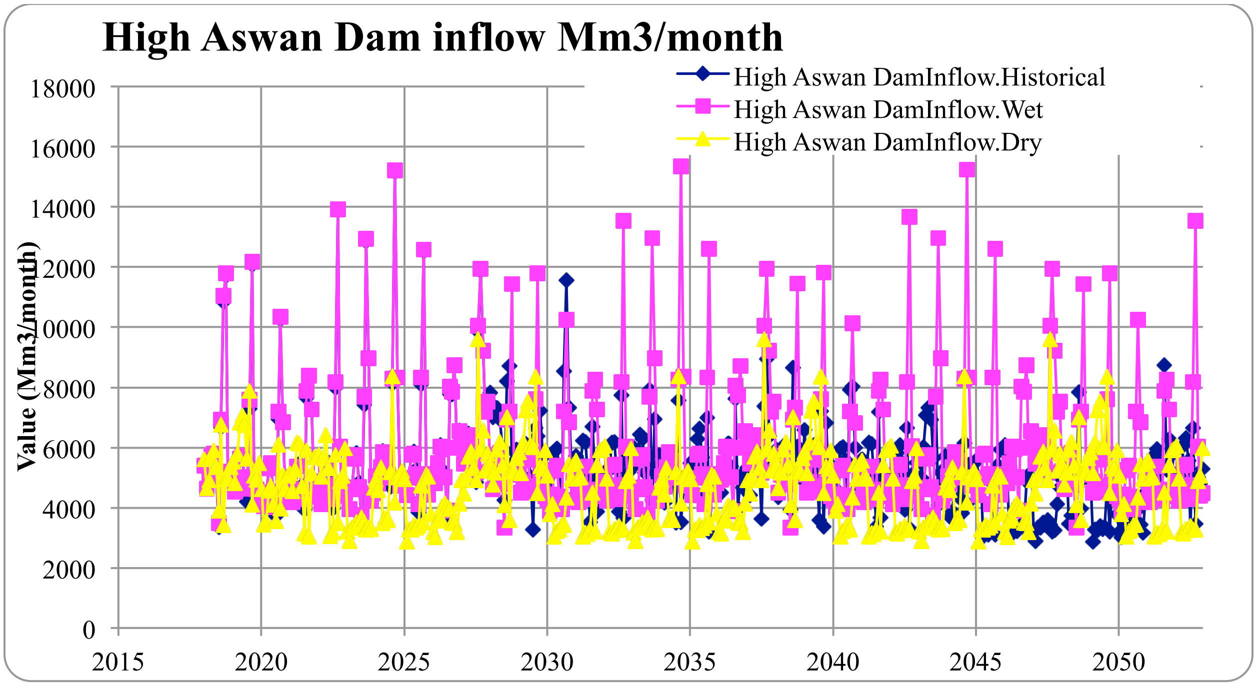

Figure 15: Inflow in to High Aswan Dam (Mm3/month) Scenario 1

Scenario 2: 620 masl for Renaissance Dam, crest level (115 m height)

Using the same approach as scenario 1 we will investigate the response of the infrastructures to the different climate change scenarios. But in this case we will consider lower volume for the Renaissance dam i.e Dam crest level at 620 meters above sea level or height of 115 m. Similar to the previous scenario we are assuming the dam to be at full supply level at the start of the simulation.

(A) Power production at Renaissance dam:

Since GERD is the most upstream reservoir considered in the analysis it's expected to be affected more by climate change scenarios than the downstream reservoirs and water users.

	Percent Exceedance	
Climate Scenarios	1,007,000 MWH/Month (Threshold Value)	1,105,000 MWH/Month (Threshold Value)
Historical	66.6 (2/3)	33.3 (1/3)
Wet	69	33.3
Dry	65	33.3

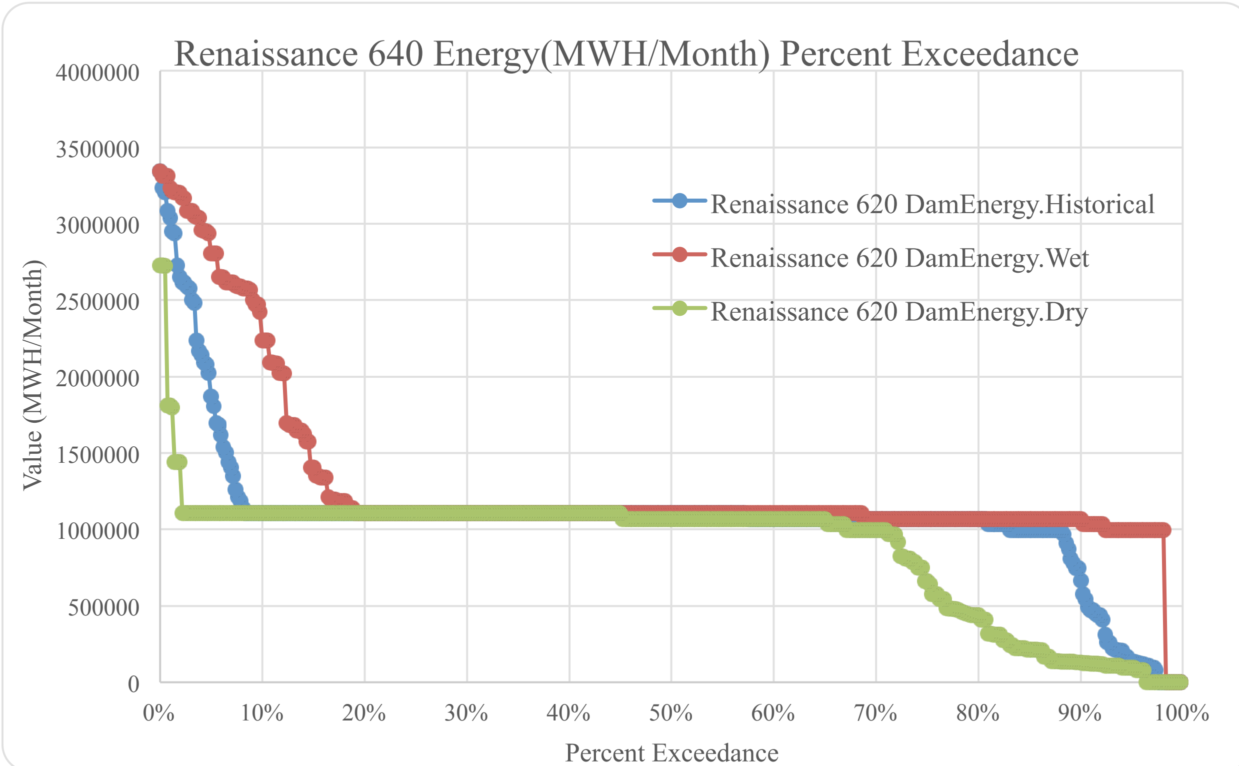

Figure 16: Renaissance Energy (MWH/Month) Percent Exceedance Scenario 2

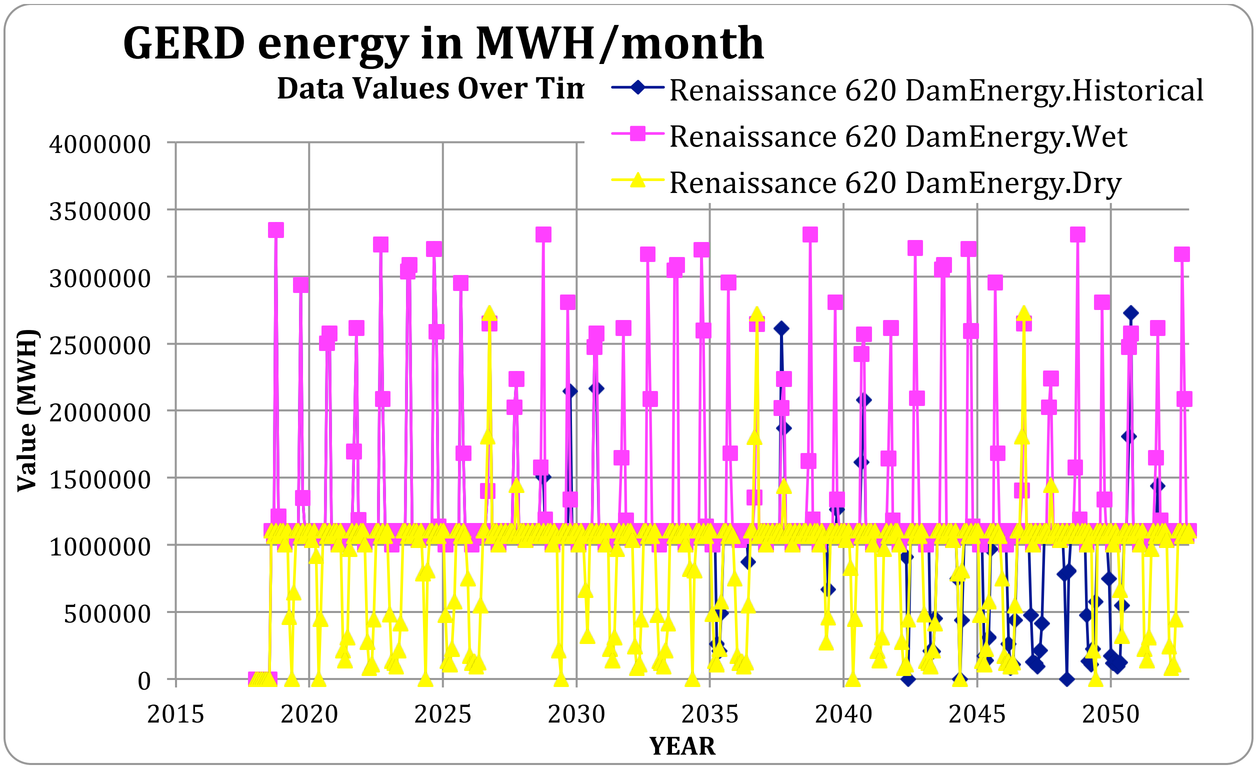

Figure 17: GERD energy in MWH/month Scenario 2

This analysis shows that the hydropower production reliability at Renaissance dam is highly sensitive to climate change scenarios. Notice also the difference in sensitivity to the dry climate change scenario from Scenario 1 because of the capacity of the hydropower plant. For scenario 2 we simulate moderate sensitivity to dry climate, while for scenario 1 we simulate relatively high sensitivity.

	Percent Exceedance	
Climate Scenarios	134,990 MWH/month (Threshold Value)	667,666 MWH/month (Threshold Value)
Historical	95	90
Wet	98.5	99
Dry	87	75

(B) Hydropower generation at Rosaries Dam:

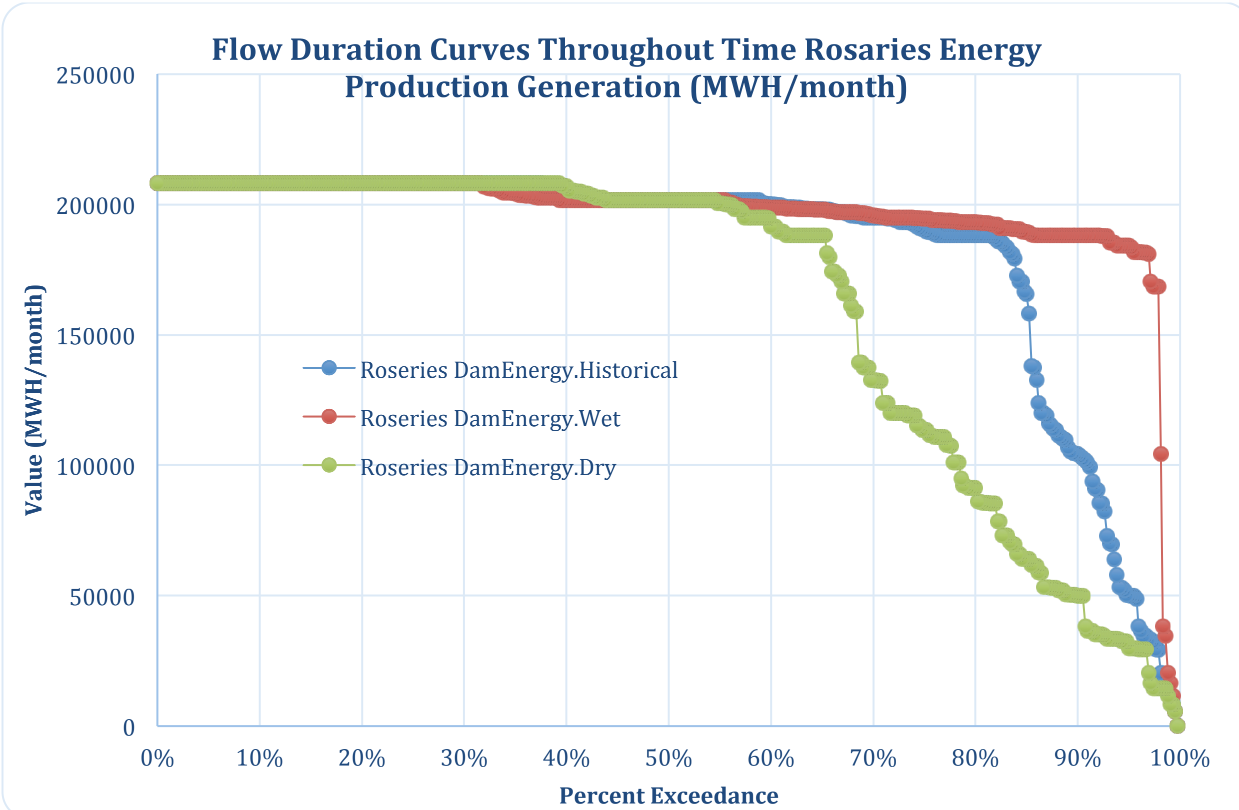

Figure 18: Flow Duration Curves throughout Time Rosaries Energy Production Generation (MWH/month)

	Percent Exceedance	
Climate Scenarios	196960 MWH/month (Threshold Value)	208320 MWH/month (Threshold Value)
Historical	66.6 (2/3)	33.3 (1/3)
Wet	67.5	31.5
Dry	57	39

Higher variation is observed from the Scenario 1. This shows that the hydropower production reliability at Rosaries dam increases with increase in upstream storage. This is also reflected in the higher reliability percentages.

	Percent Exceedance	
Climate Scenarios	50,217 MWH/month (Threshold Value)	104230 MWH/month (Threshold Value)
Historical	95	90
Wet	100	99.5
Dry	89	77

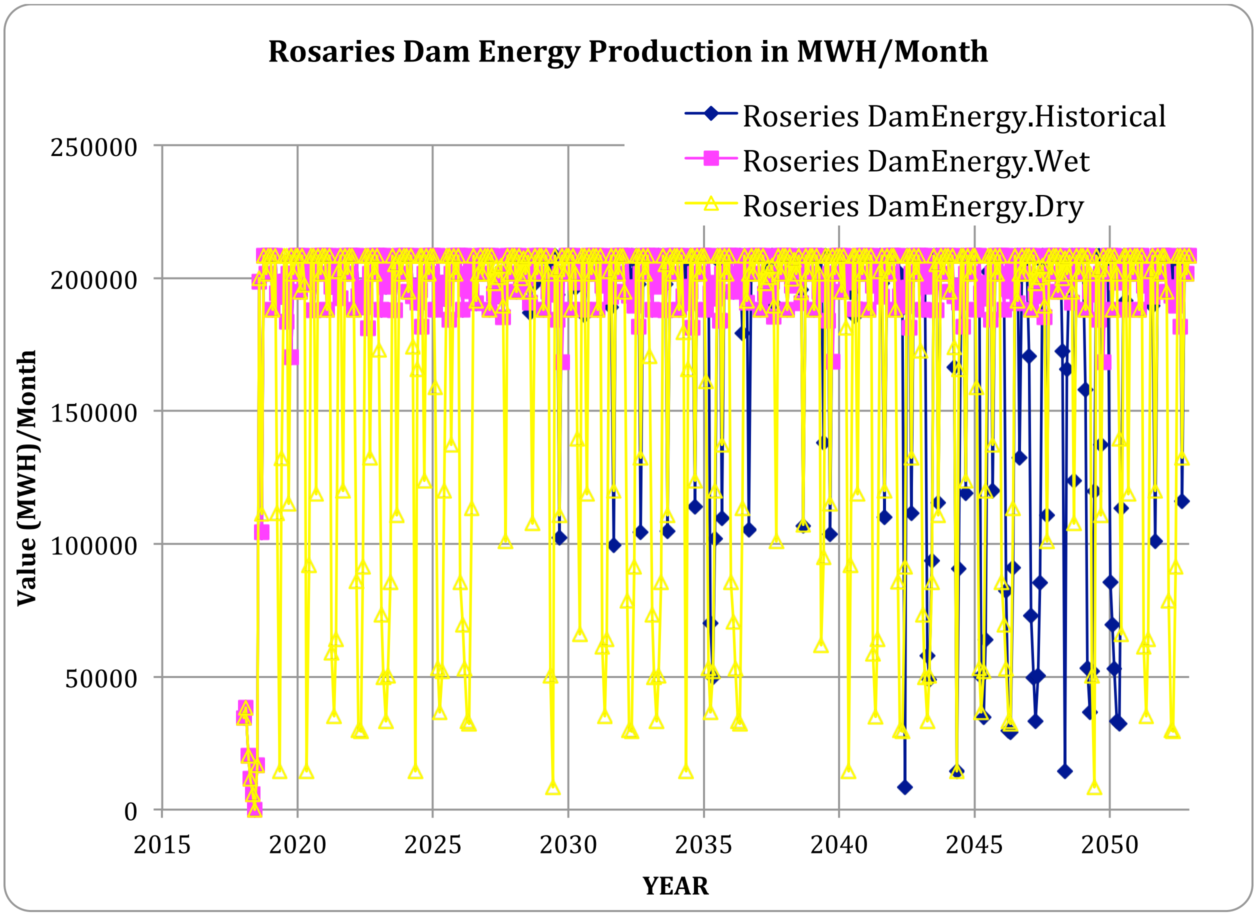

Figure 19: Rosaries Dam Energy Production in MWH/Month Scenario2

(C) Agriculture System in Sudan (irrigated):

The same approach of historical wet and dry climate change scenarios is used for analyzing the response of the irrigated sector to climate change.

The Figure shown below indicates that almost the same amount of water use is observed in all the three climate conditions for irrigated agriculture in Sudan. But when compared to the previous scenario of 640 m for GERD it shows a slight decrease in reliability especially for the higher percentiles.

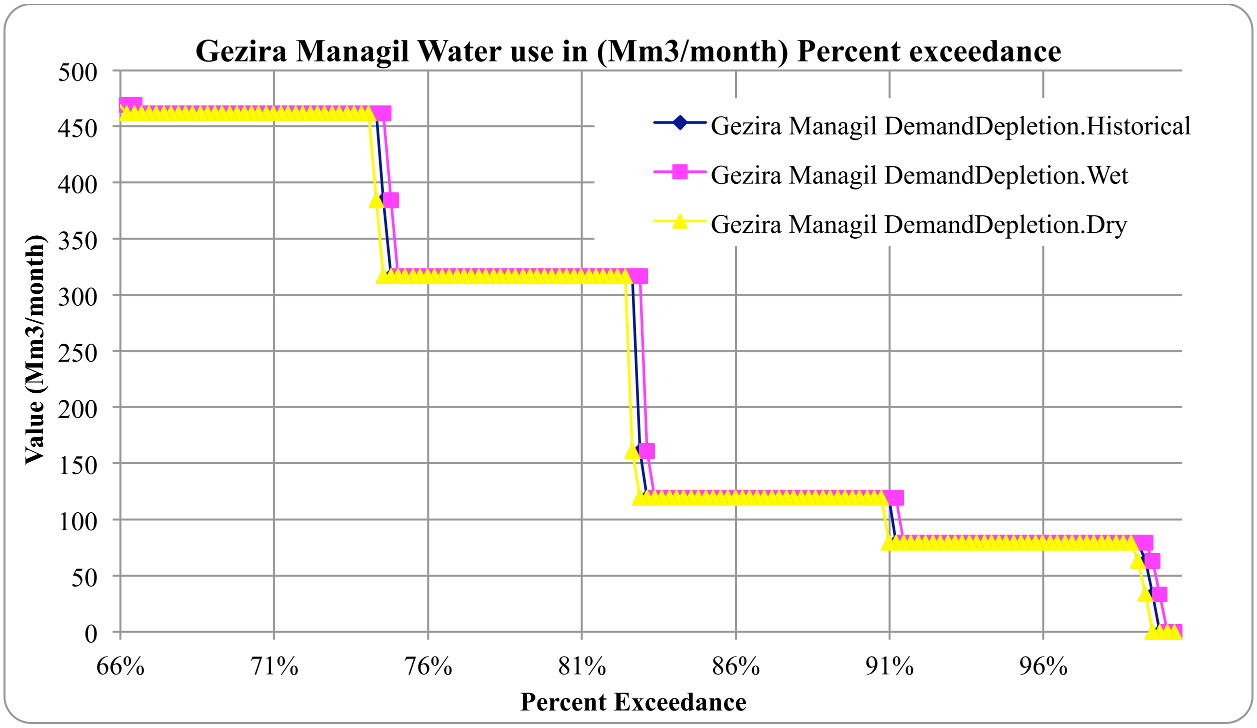

Figure 20: Gezira Managil Water use in (Mm3/month) Percent exceedance Scenario 2

For downstream Sennar uses there is no significant difference in reliability. The same as Scenario 1.

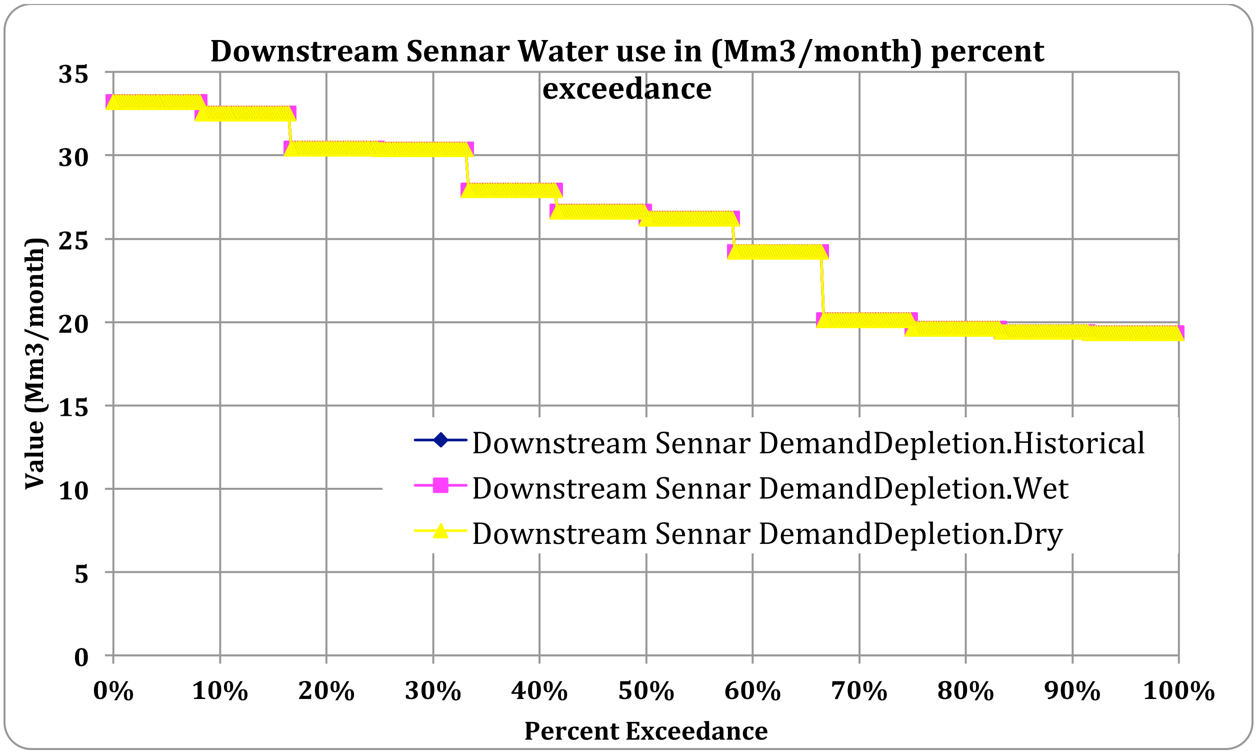

Figure 21: Downstream Sennar Water use in (Mm3/month) percent exceedance Scenario 2

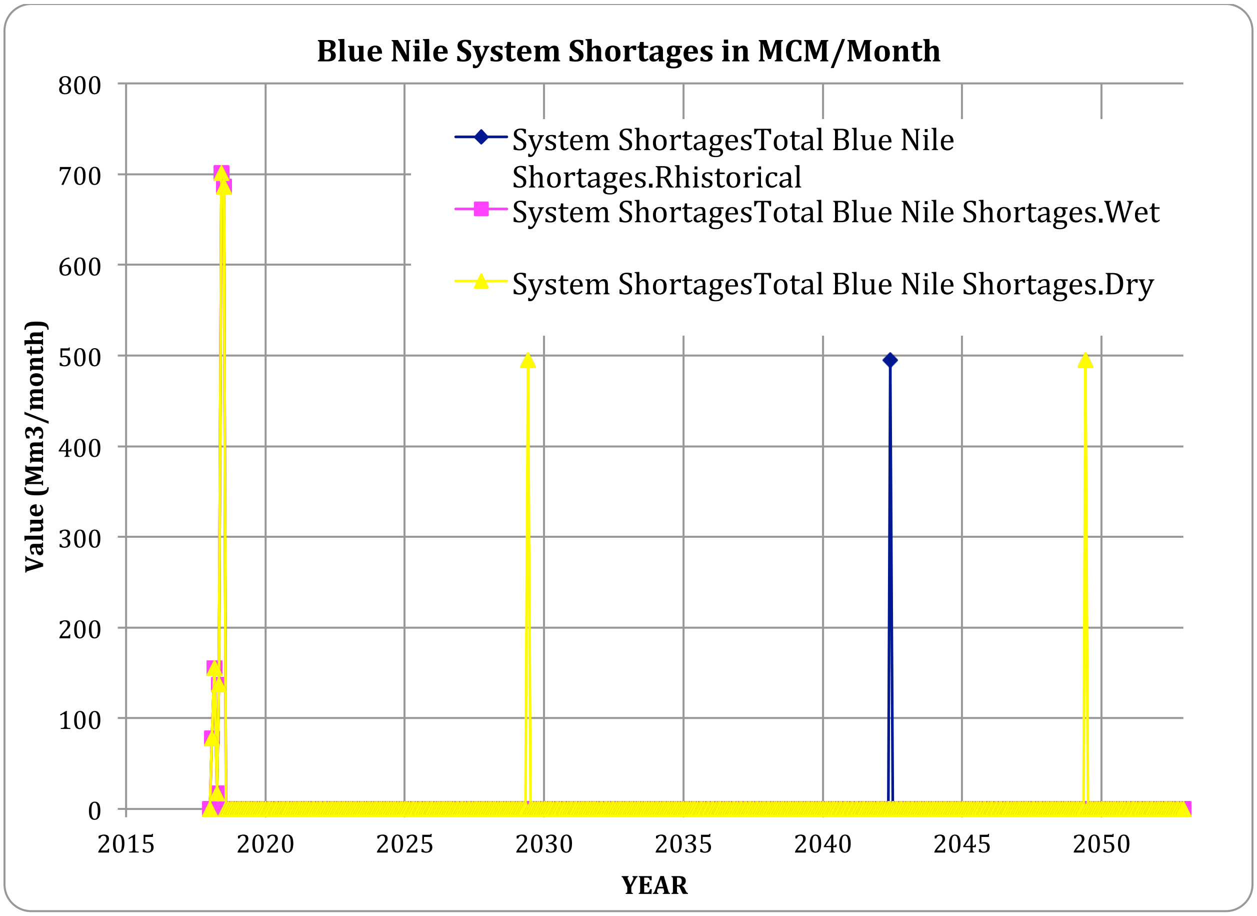

Figure 22: Blue Nile System Shortages in MCM/Month Scenario 2

System shortages are observed in this scenario unlike the previous scenario where system shortages were buffered out by the large amount of storage in the Renaissance dam.

(D) Water flow to Egypt:

Our initial assumption of full supply level for the GERD at 620 masl dictates that High Aswan dam will not be affected by filling of the GERD in this simulation, hence we can assume 173masl for initial water level behind the High Aswan dam.

	Percent Exceedance	
Climate Scenarios	4,700 MCM/Month (Threshold Value)	5,700 MCM/Month (Threshold Value)
Historical	66.6 (2/3)	33.3 (1/3)
Wet	70	38
Dry	49	17

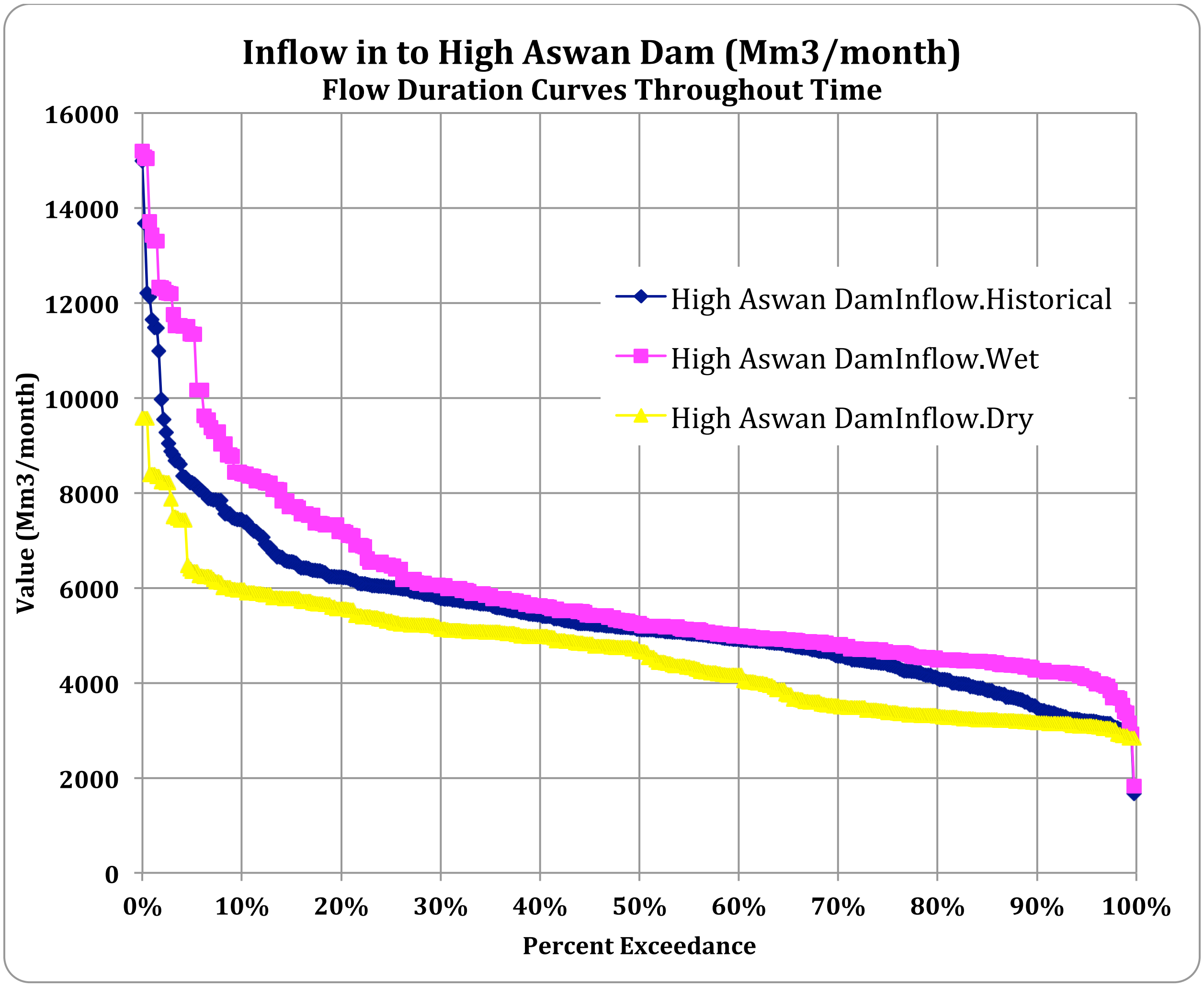

Figure 23: Inflow in to High Aswan Dam (Mm3/month) Scenario 2

Figure 22 indicates that wet climate scenario results in high inflow to the High Aswan Dam and dry climate scenario results in reduction of inflow to the dam. Note all the three graphs (scenarios) shown above assume 620 masl of dam crest level for GERD and full level when simulation starts.

We can also see when compared to the previous scenario of 640 masl for GERD crest level, there is no significant change in the flow reliability at High Aswan Dam.

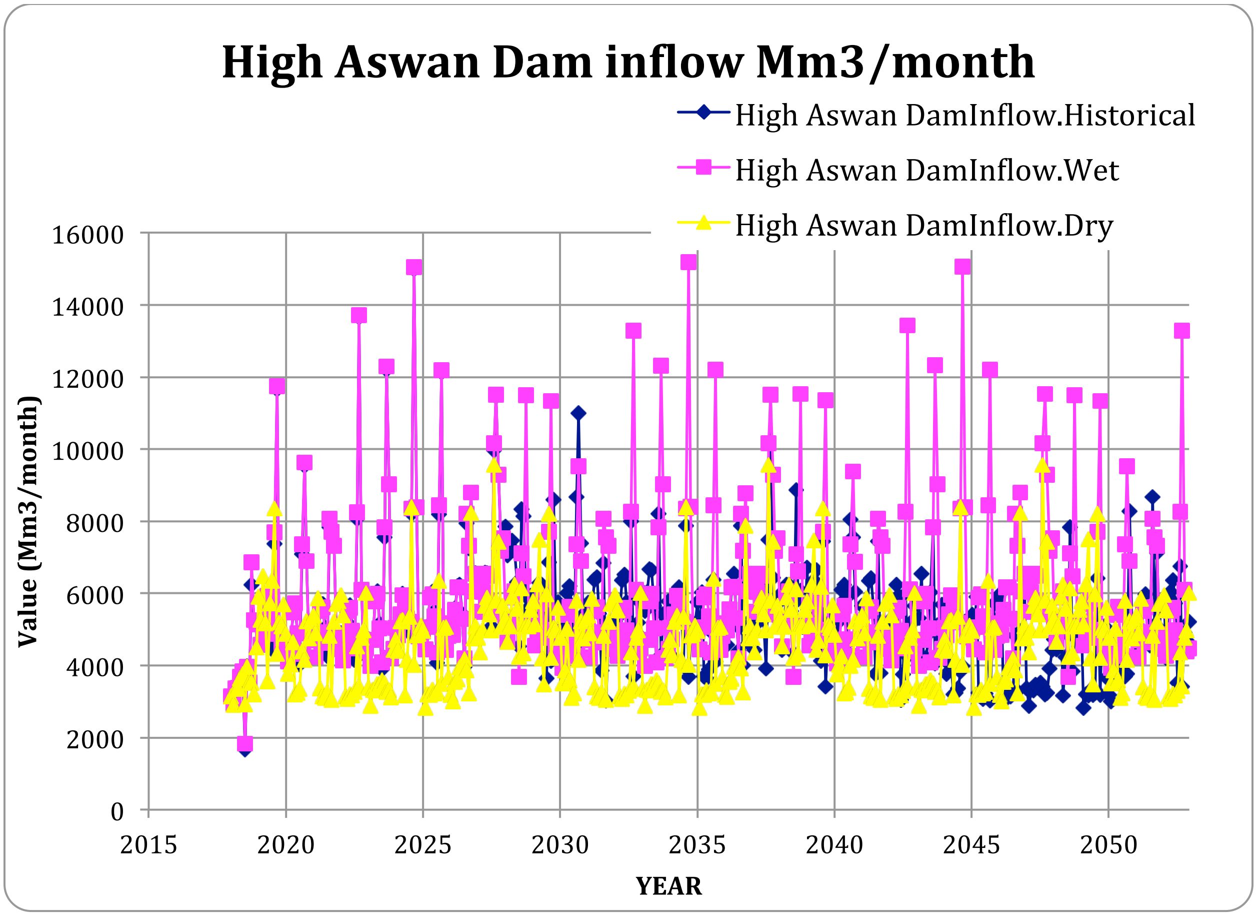

Figure 24: High Aswan Dam inflow Mm3/month Scenario 2

4.0 Conclusions

Indicators	High GERD (135 meters)		Low GERD (115 meters)	
	Dry	Wet	Dry	Wet
(A) Power from GERD	High	Low	Medium	Low
(B) Power from Rosairis	Medium	Low	Medium	Low
(C) Irrigation in Sudan	Low	Low	Low	Low
(D) Flow of Water to Egypt	High	Medium	High	Medium

Summary of the Results of the Analysis on the Impact of Two Climate Change Scenarios, assumed under two Infrastructure Investment Scenarios.
High, Medium and Low refer to the level of sensitivity to Climate Change.

The above table summarizes the results of this sensitivity and risk analysis. The power generation of the GERD and the flow of water to Egypt are the most sensitive compared to the indicators in Sudan. This is particularly true for the dry climate scenario. These results are dictated by the fact the GERD offers a buffer to the hydropower and irrigation systems in Sudan which, in general, have low water demands. The GERD is most at risk to the possibility of dry future climate, especially if the large capacity option is adopted. The flow of water to Egypt is vulnerable by virtue of location at the bottom of the overall system.

Appendix

Questionnaire

Name: ………………… ……..   Country: ……… ………………….

(A) **ASSESSMENT OF CURRENT INSTITUTIONAL CAPACITY IN THE EASTERN NILE COUNTRIES:**

(1) Key stakeholders in each country who are commissioned or expected to carry CRA in the context of water resources planning and management:

………………………………………………………………………………………………

(2) The capacity of these stakeholders (human, and technology) to carry or interpret CRA analysis in this context:

…………………………………………………………………………………………….

(3) Gaps in capacity between needed and available resources,

……………………………………………………………………………………………..

(4) Existing level of coordination between stakeholders at different sectors within the same country, and at the regional level:

…………………………………………………………………………………………….

(5) Strategies to enhance institutional capacity for CRA in the context of water resources planning and management:

……………………………………………………………………………………………

(B) RANGE OF THRESHOLDS FOR SYSTEMS PERFORMANCE INDICATORS:

describing limits between 3 states (High, Normal, Low; or in other words hydrologic conditions of Flood, Normal, and Drought, or describing economic conditions of Plenty, Sufficient, and Deficient). We propose these thresholds correspond to conditions that are experienced historically 1/3, 1/3, and 1/3 of the time.

Reaction (………) Agree (………..) Disagree (………………….) Alternative

<u>(C) STRATEGIES TO COPE WITH HISTORICAL VARIABILITY:</u>

What strategies, if any, do the stakeholders responsible for CRA within the water sector use to cope with significant historical events of climate variability (major droughts e.g 1983-84; major floods such as 1998, and 2008)?.

……………………………………………………………………………………………….

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Are these strategies evolving with time to adapt to the likelihood of climate change?

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<u>(D) TRENDS IN INFRASTRUCTURE DEVELOPMENT</u>:

Are there any trends in infrastructure development & management in the system defined above?

……………………………………………………………………………………………….

What are the most significant investments in the last 10 years?

……………………………………………………………………………………………..

And in the coming 10 years?

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