Nile Basin Initiative

Eastern Nile Technical Regional Office (ENTRO)

Nile Cooperation for Results (NCORE)

Climate Risk Assessment Study

Consultancy Service

By

Elfatih A B Eltahir

Report on

Identification of Eastern Nile Systems Sensitivity to Historic Climate Variability and Historic Coping Strategies

November 2014

Table of Contents

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 look back and identify system sensitivity to historic climate variability and examine historic coping strategies

2.0 Review of historical variability and recent trends:

Natural variability in the hydrology of the Nile has been of interest to society for long time. The early stories in the Bible and the Koran about years of scarcity and years of plenty, related to the flooding of the Nile, point among other things to the importance of historical variability of the Nile hydrology to the people who lived in the region, even thousands of years ago. The climate variability at time scales of millennia has been recorded in the paleoclimatic observations that document the contraction and expansion of the Sahara desert, as the rainfall levels oscillate in response to changes in the orbital parameters that impact solar forcing of the climate system.

In more recent history, and at time scales of hundreds of years the variability of the hydrology of the Nile has been recorded as part of the history of the region and its people. The famine of 1888 in Sudan, and the famine of 1983/84 in Ethiopia are examples for how historical variability in the Nile hydrology left a significant impact on society, at the time scale of centuries.

At the other end of time scales, variability in the hydrology of the Nile at the time sales of months is quite predictable, with flooding during summer and low flow in winter.

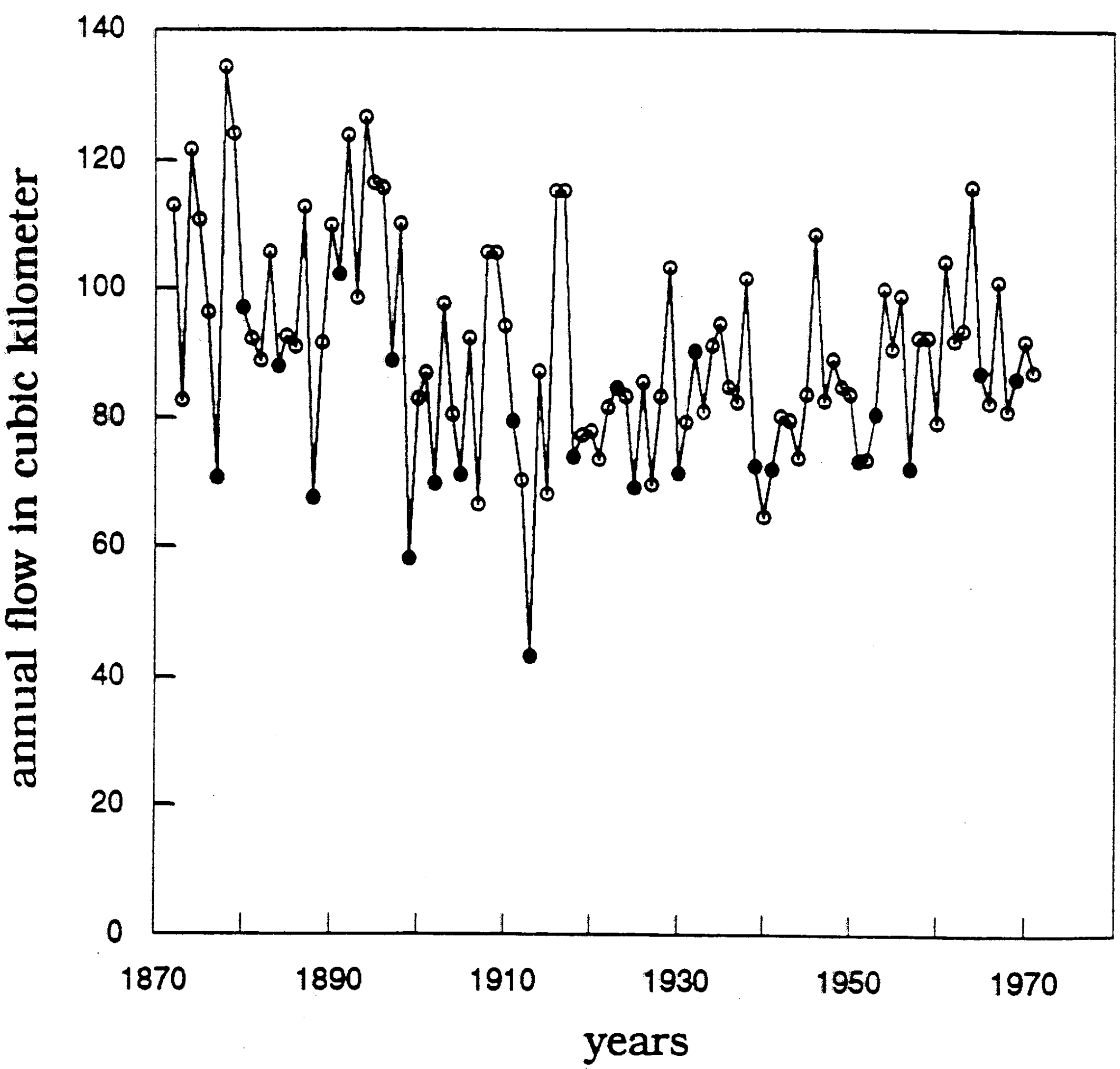


Figure (1)

In between, the inter-annual variability in the hydrology of the Nile, leading to the occurrence of wet and dry years is one of the main challenges. In some years, the flow in the river and the rainfall over the basin are relatively high leading to flooding, damage to crops and property; in other years drought conditions prevail leading to significant suffering. Figure (1) above describes this pattern of inter-annual variability as experienced in the flow of the river in Aswan.

Until recently, the inter-annual variability in the hydrology of the Nile has been considered random and unpredictable. Recent research has made progress in explaining this natural variability (Eltahir, 1996, Water Resources Research). We now recognize that occurrence of floods and droughts in the Nile basin is associated with the El Nino phenomenon, such that droughts are associated with warm conditions in the Pacific ocean and flooding conditions are associated with relatively cold sea surface temperature in the same region. The filled circles in the above figure correspond to El Nino years, which are clearly associated with the major droughts, including the record drought of 1914.

In a more recent paper, Siam et al. (2014, Climate Dynamics) describe a similar role for the Indian Ocean in shaping historical variability of floods and droughts over the Nile basin. Warming of temperature in the southern Indian Ocean is associated with occurrence of droughts in the Nile basin. This relationship seems independent of the El Nino-Nile teleconnection. The discovery of these teleconnections between the Nile hydrology and the global oceans has important implications to how institutions in the Nile basin may cope with occurrence of droughts and floods.

The following set of Figures (1 and 2) describes time series for annual precipitation, maximum annual precipitation for Addis Ababa. Clearly, these two time series show no significant trend.

Similarly Figures (3 and 4) describe the annual river flow, and maximum annual river flow at Eldiem station at the Sudan/Ethiopia border. Both series show somewhat increasing trends of rather small magnitude. Given the absence of a significant trend in rainfall, the trend in river flow may have to do with changes in land cover, rather than a reflection of a global climate change.

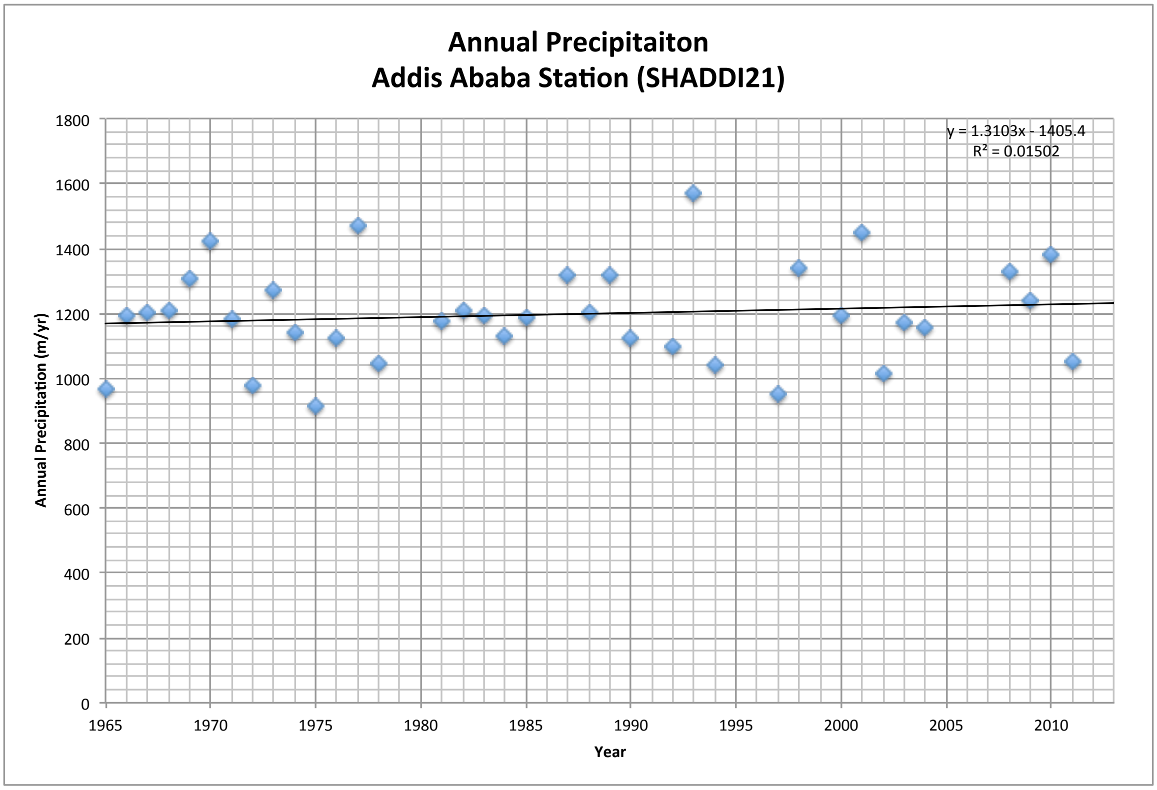


Figure 1

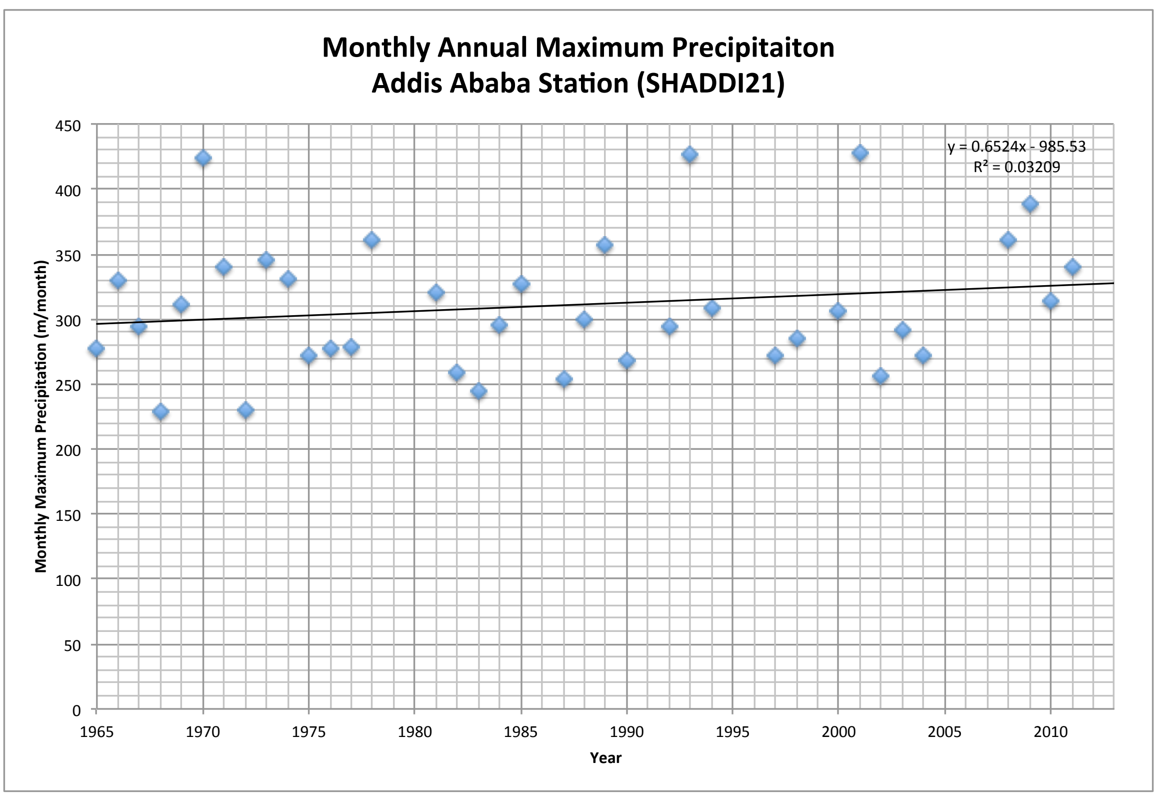


Figure 2

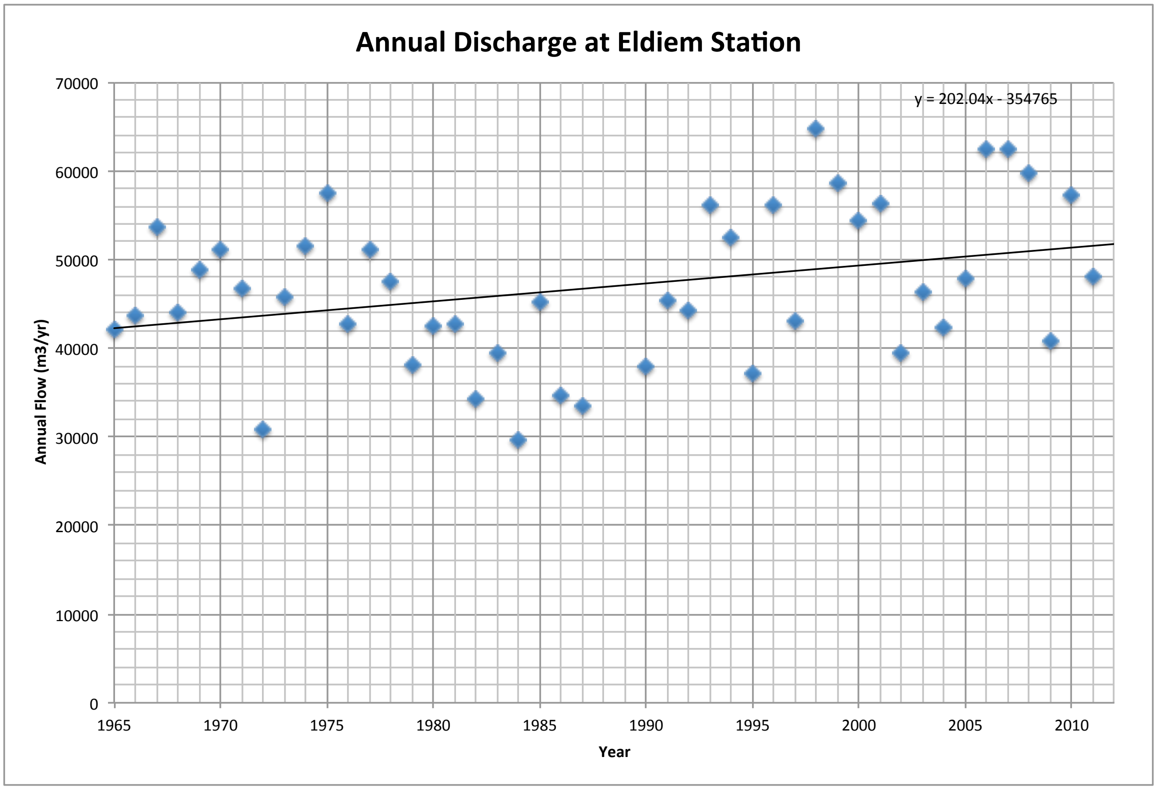


Figure 3

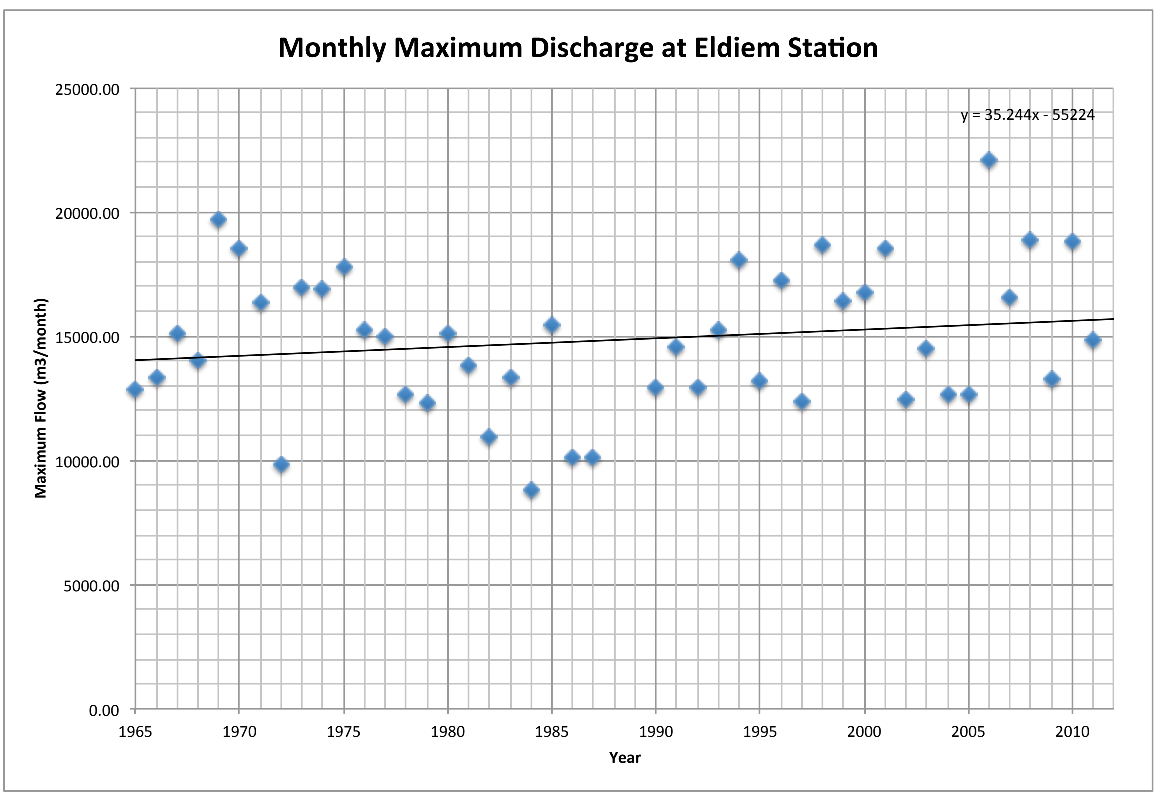


Figure 4

3.0 Analysis of historical time series of hydro-meteorological records:

Climate variability has been one of the main challenges for the development of the Eastern Nile (EN) water resources trough out history. If we look at the last 60 years of hydrology in the Nile, several droughts and floods of different magnitude had affected the region and its water resources. The Blue Nile River and its associated infrastructure, being the major water supplier for the Nile, has been the first to be impacted by this variability. Here, a water resources model developed under the Eastern Nile Planning Model has been used to test the resilience of this infrastructure. The RiverWare model was configured to simulate potential future conditions (the period from 2018 to 2052), assuming the 35 years of naturalized historical hydrologic data from 1956 to 1990. The selection of a specific time frame for the analysis was dictated by two major factors. One is the availability of continuous, reliable hydrological data with full spatial coverage over the region. And the second is inclusion of the extreme events in the recent hydrology of the river. This specific period provided full spatial coverage in terms of data, and included the dry sequence of years, wet sequence of years and also the average sequence of years that occurred in the basin in recent history.

This analysis will investigate the response of the agricultural systems in Ethiopia (rain-fed) and in Sudan (irrigated) and existing and planned dams to historical variability in the basin. Specifically we will focus on hydropower production in Rosaries dam, Renaissance dam and water availability and energy production at High Aswan Dam in addition to aggregated analysis of the irrigated and rain-fed agricultural activities.

3.1 The existing system and hydrological variability (Baseline Scenario):

The model was setup to represent the current configuration of water use and infrastructures in the basin using the hydrological flow for the period 1956-1990. It covers the entire EN basin and includes all existing large-scale water infrastructures with their operation rules.

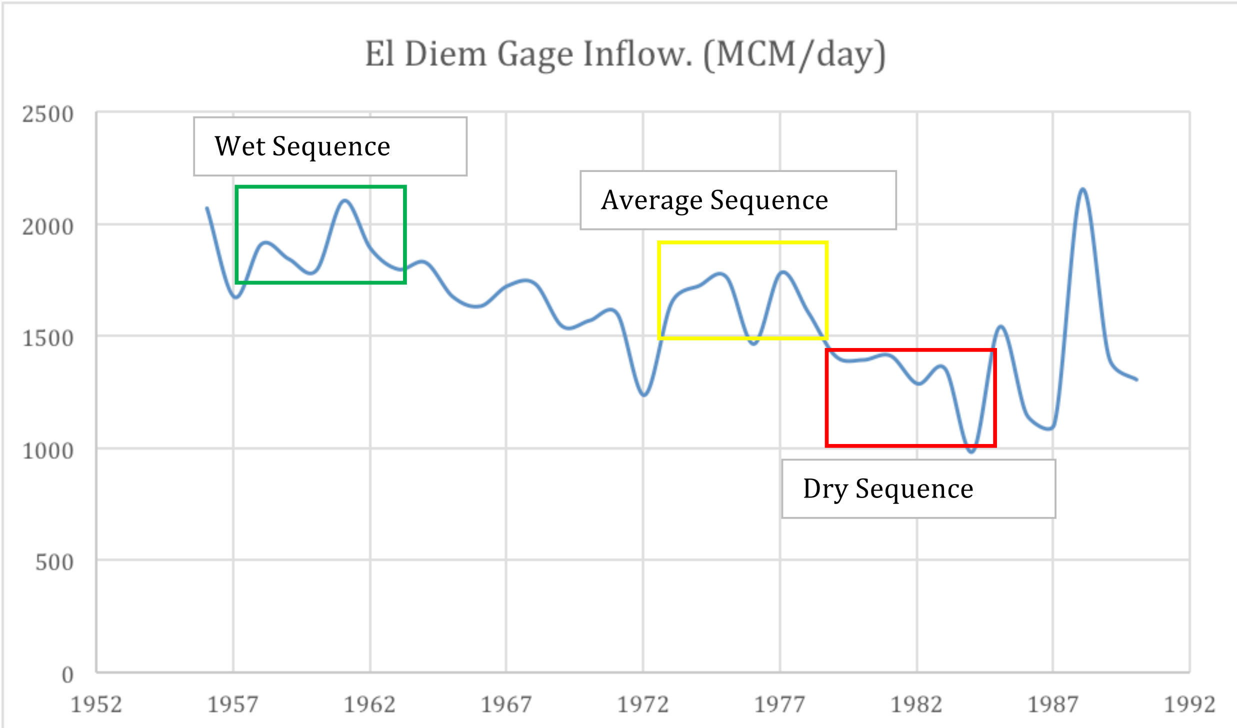


Figure 5 El-Diem Gage flow

As stated earlier the historical data that was used in the model was from 1956-1990. The baseline model and scenario model were configured to simulate the period from 2018 to 2052 using the historical data mentioned above. A monthly time step was selected, as the focus of the study is to investigate the long-term responses rather than real time operations of the structures.

Hydropower generation at Rosaries Dam:

Rosaries Dam was built in 1966 to serve the purposes of hydropower generation, irrigation and flood retention 1950, in the town of Rosaries on the Blue Nile, about 500 km southeast of the Sudanese capital of Khartoum. The 280 MW hydroelectric plants located at the dam supplies nearly half of Sudan's power output, though generation varies greatly through the year with changing flow of the river. The dam also provides irrigation for the Gezira Plain. The lake resulted from the dam construction is 80 km in length and total area of 280 km with maximum depth averaging 50 meters, the area is expected to increase after the dam heightening is completed. This dam recently went under a heightening project for the crest, hence increasing its storage capacity.

Figure 6 Rosaries dam, photograph by SUNA, Sudan Vision 2012

Under the baseline scenario Rosaries dam generates the peak or installed capacity of 280 MW during the rainy season (July, August, September and October) and significantly drops below 100 MW during April and May. This is due two both availability of water and the operation regime of the dam.

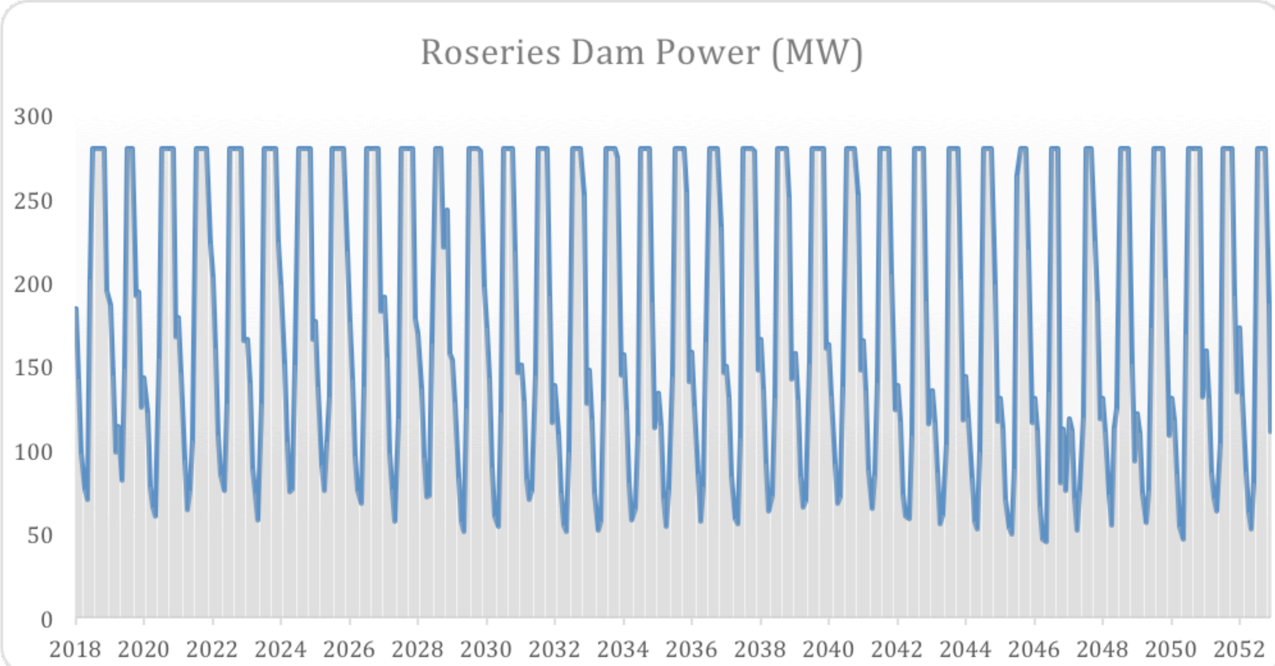


Figure 7 Rosaries Dam Power (MW)

In order to study the inter-annual variability in the hydropower production annual energy generation was plotted against time and the long-term average. As shown in figure 8 below the annual energy generation is highly affected by the hydrology and higher around the wet sequence of years lower during the dry sequence of years and close to the mean 1555 GWh during the average flow years.

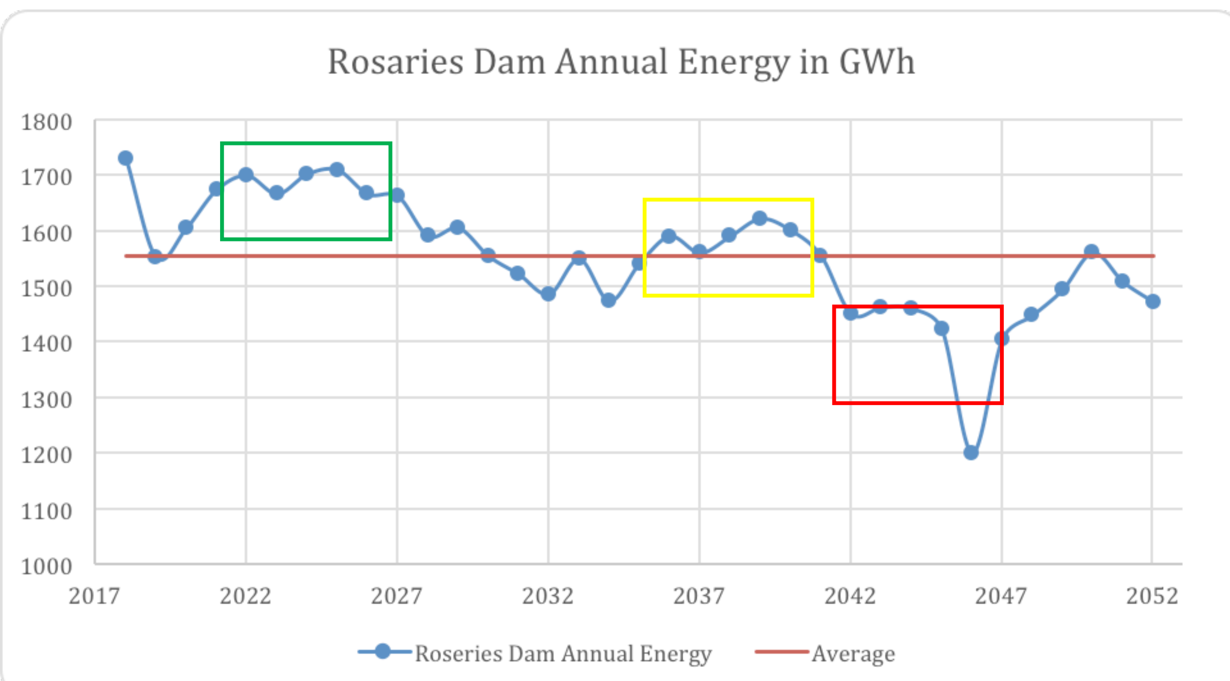


Figure 8 Rosaries dam annual energy generation (GWh)

The reliability of the power generated is a major criterion for hydropower plants. The reliability of the power generated at Rosaries Dam is shown in Figure 9.

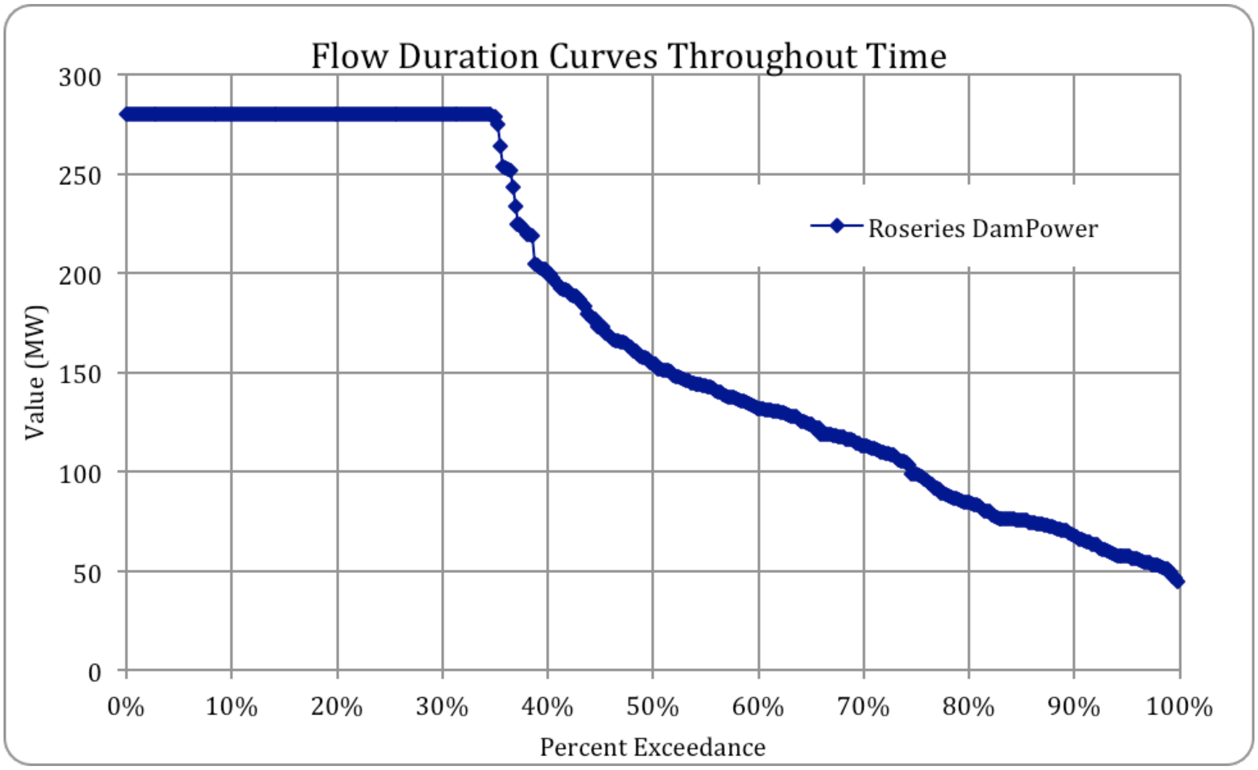


Figure 9 Reliability of the Power generated at Rosaries dam (Base case)

Agriculture System in Sudan (irrigated):

The modeled results of agricultural water use in the Blue Nile and Sudan as a whole are summarized below.

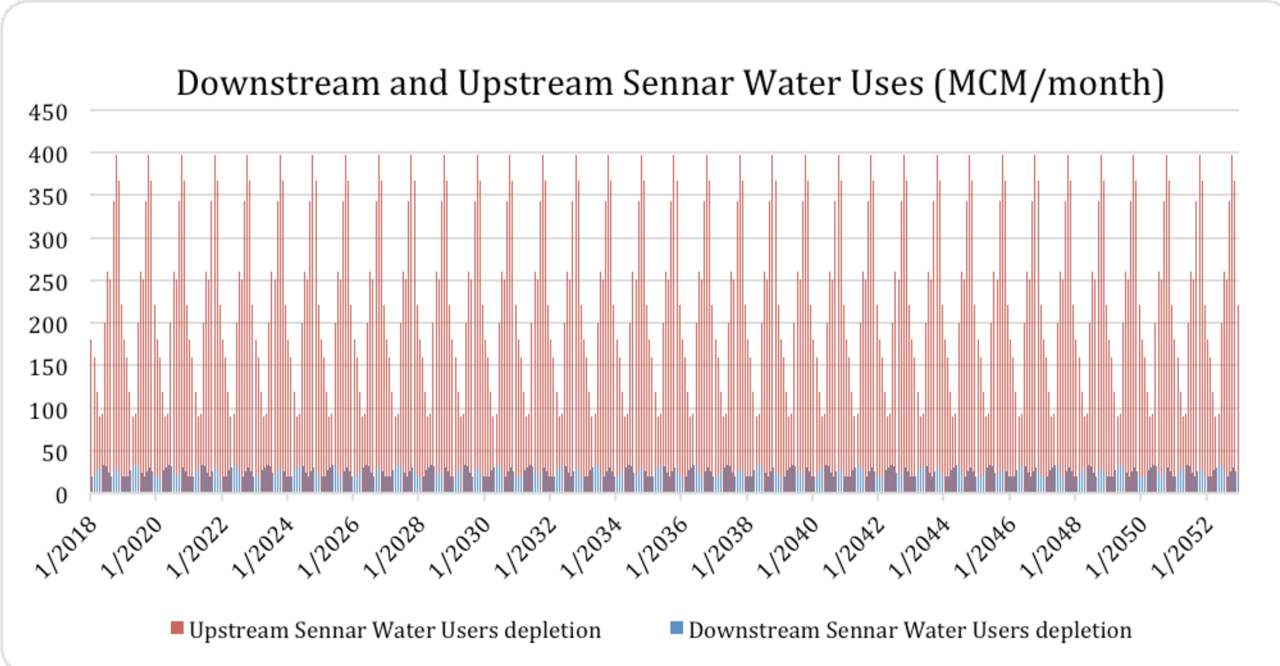


Figure 10 Upstream and downstream Sennar water users' depletion (consumption) in MCM/month

The Gezira scheme demands are the biggest water user in the Blue Nile serving the 0.88 million ha of irrigated land.

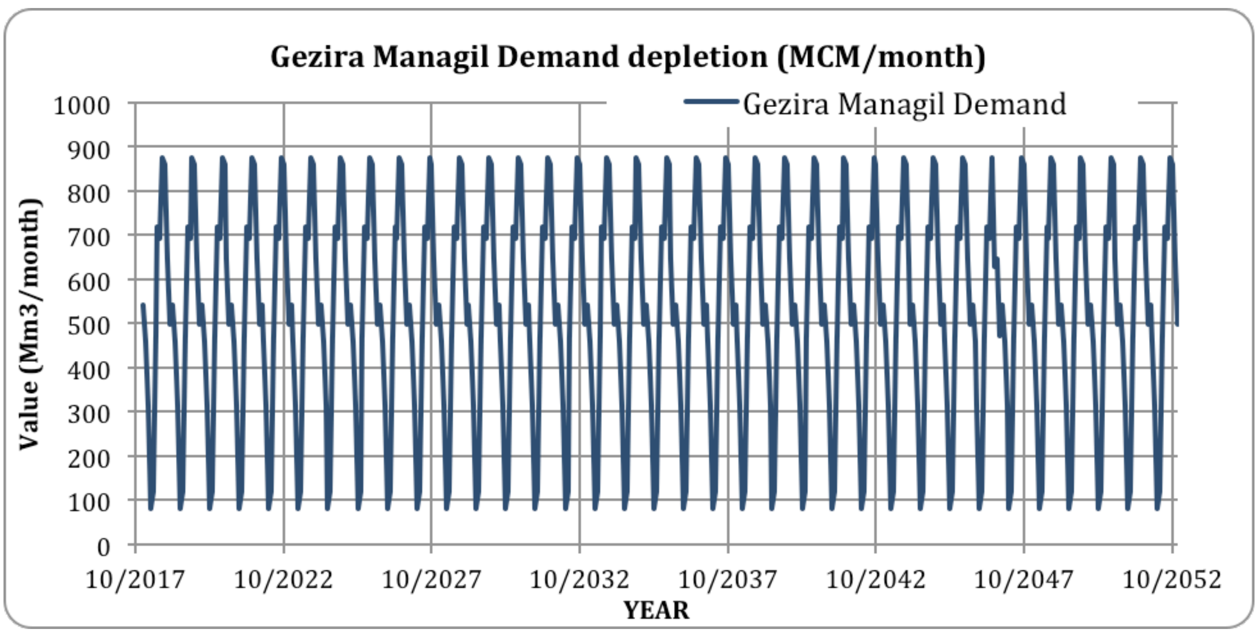


Figure 11 Gezira Managil Demands depletion in MCM/month

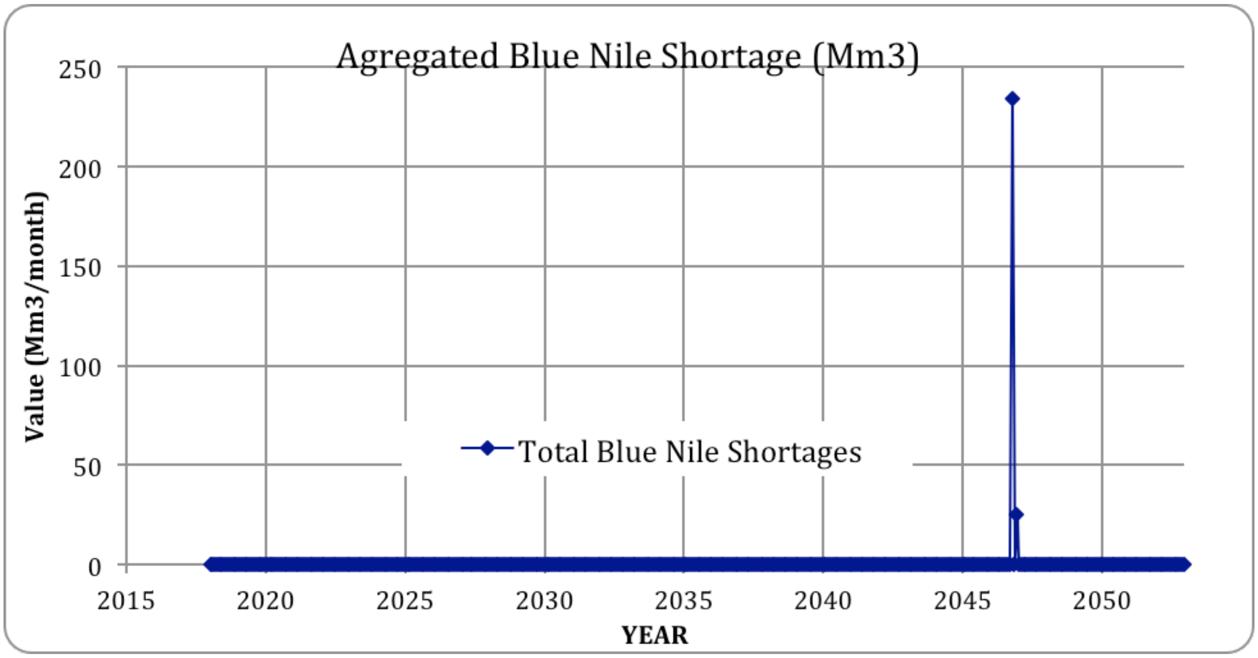


Figure 12 Aggregated Blue Nile Shortages in MCM/month

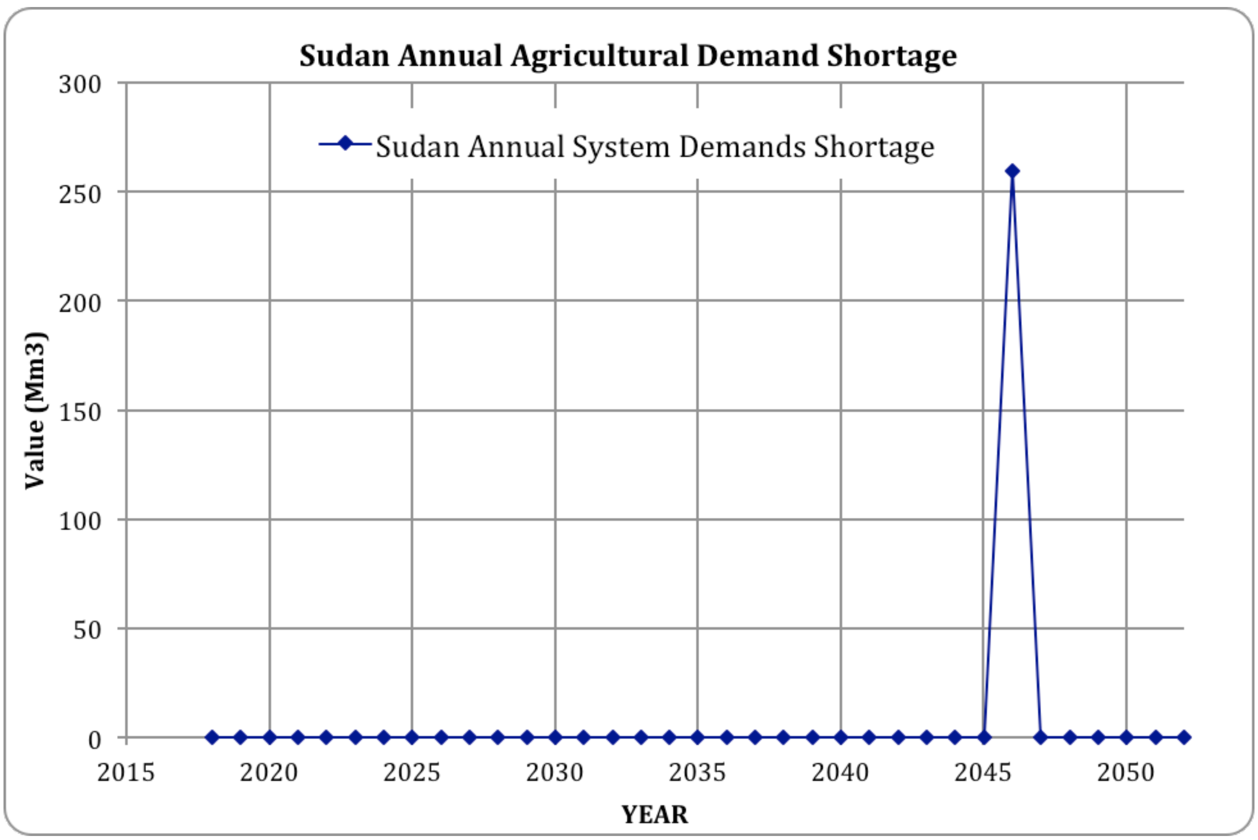


Figure 13 Total Sudan Shortages in Mm3/month

Water flowing to Egypt:

The high Aswan Dam acts as a buffer for the Nile waters before entering the Egyptian delta. Hence the inflow into the High Aswan Dam is considered as the water reaching Egypt.

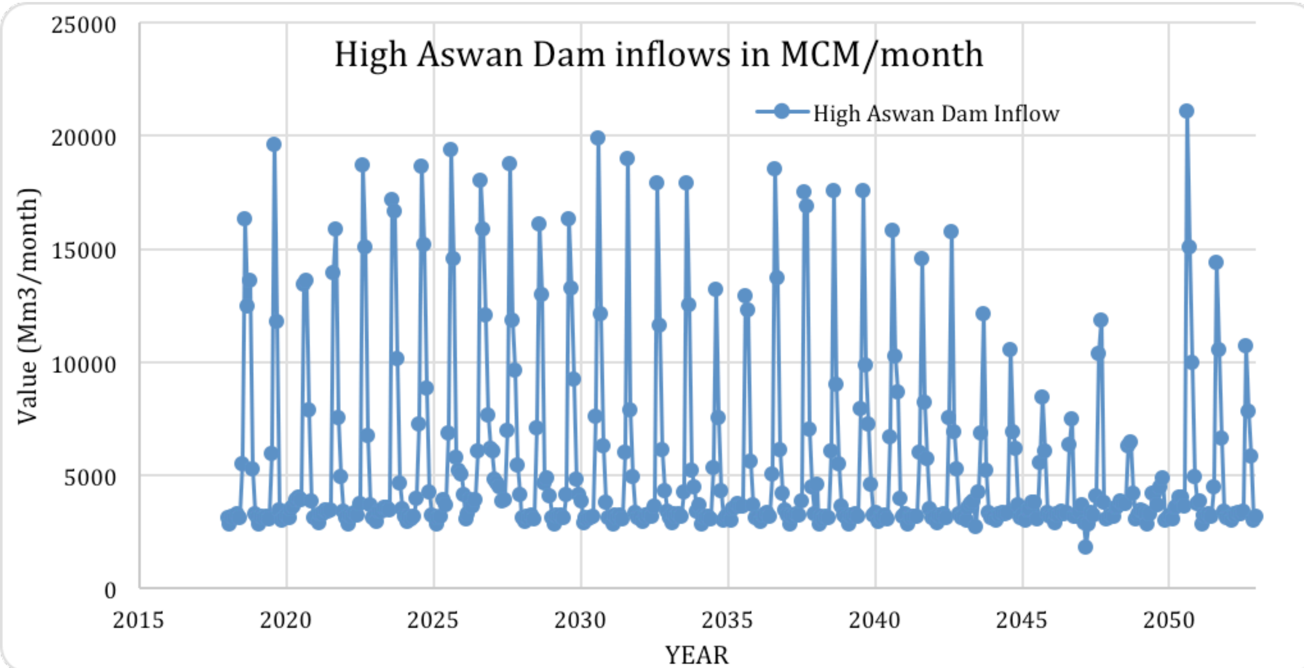


Figure 14 High Aswan Dam inflows in MCM/month

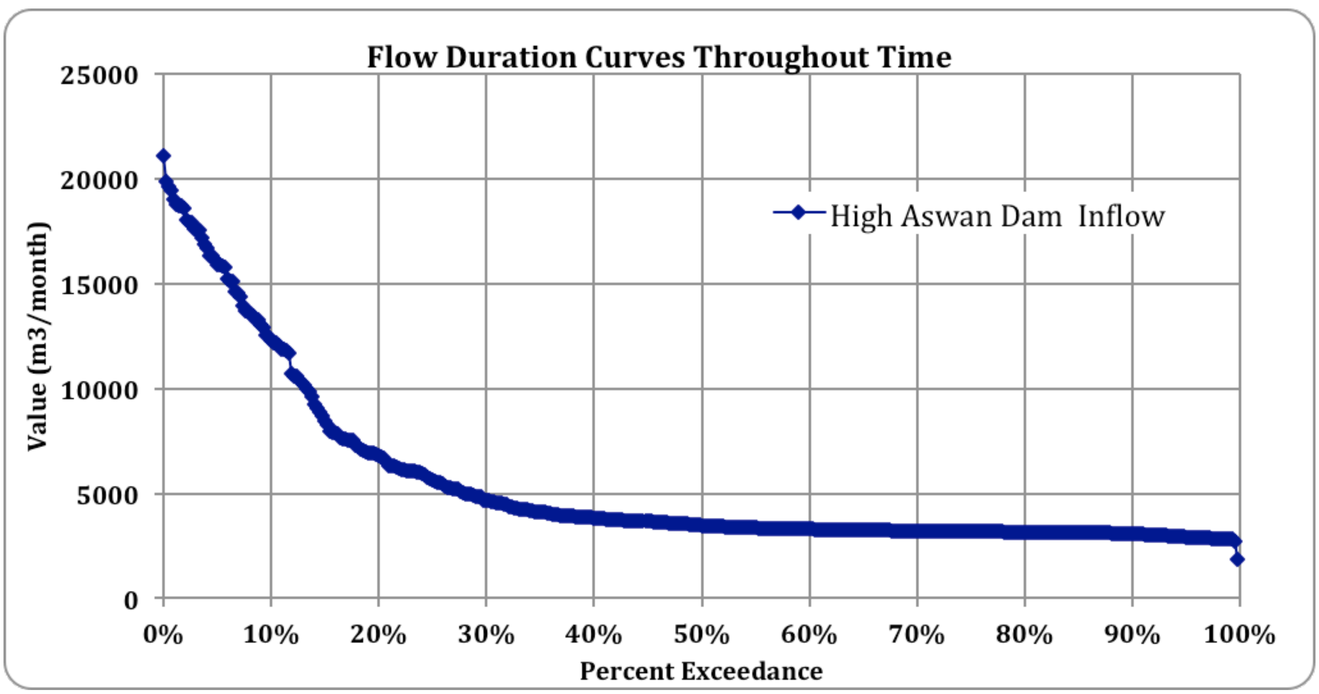


Figure 15 Reliability of flow at High Aswan Dam

3.2 Historical hydrological variability & Renaissance dam: (Scenario 1)

The construction of the Great Ethiopian Renaissance Dam (GERD) started April 2011. Since then the biggest hydropower plant in Africa progressed to about 32% into the construction phase. This massive infrastructure will change the flow regime of the region and is expected to generate 6,000 MW of electricity. Hence it's important to investigate how this structure will perform under hydrological variability and its possible contribution for buffering some of the variability.

Grand Ethiopian Renaissance Dam	
Country	Ethiopia
Location	Benishangul-Gumuz Region
Coordinates	11°12′51″N 35°05′35″ECoordinates: 11°12′51″N 35°05′35″E
Purpose	Power
Status	Under construction
Construction began	April 2011
Opening date	July 2017[1]
Construction cost	$4.8 billion USD
Owner(s)	Ethiopian Electric Power Corp
Dam and spillways	
Type of dam	Gravity, roller-compacted concrete
Impounds	Blue Nile River
Height	170 m (558 ft)
Length	1,800 m (5,906 ft)
Reservoir	
Creates	Millennium Reservoir
Total capacity	73×109 m3
Power station	
Commission date	2018 (planned)
Turbines	16 x 375 MW Francis turbines
Installed capacity	6,000 MW(max. planned)
Annual generation	15,692 GWh Est

For this analysis a 6 years filling strategy and 173 meters pool elevation level for the High Aswan dam has been assumed.

Energy generated at GERD

The dam on average generates 15200 GWh of energy annually.

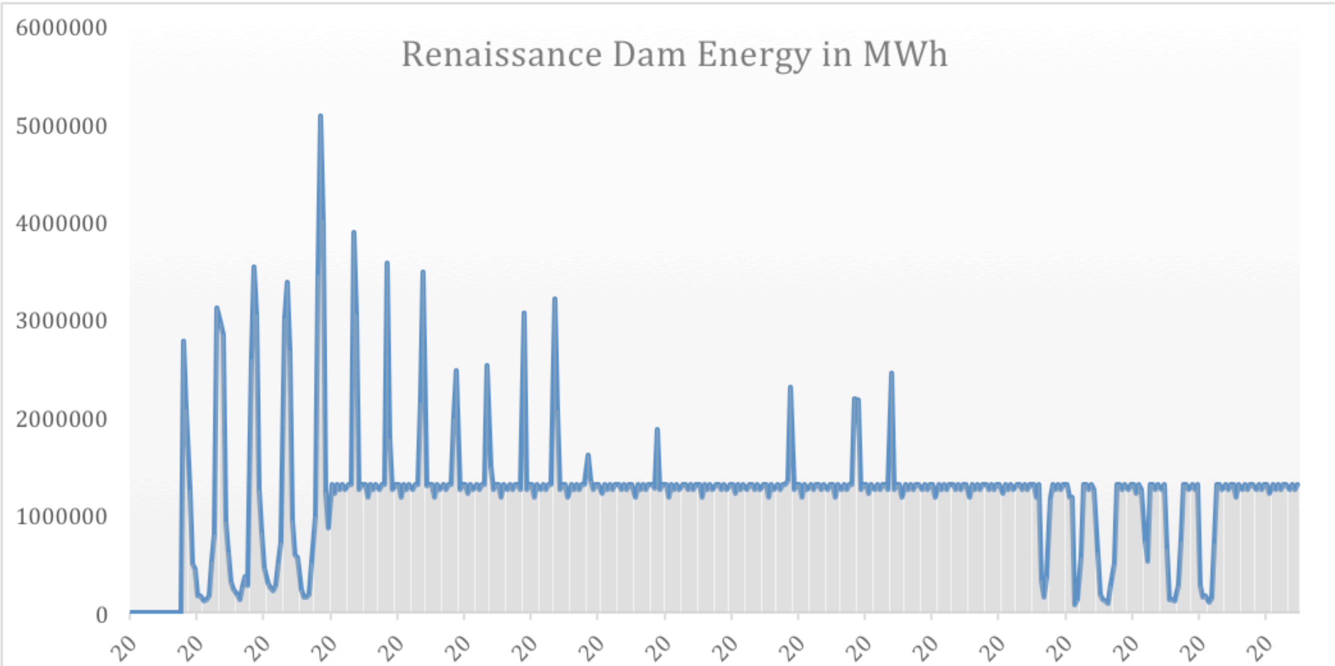


Figure 16 Energy Generated by the GERD in MWh

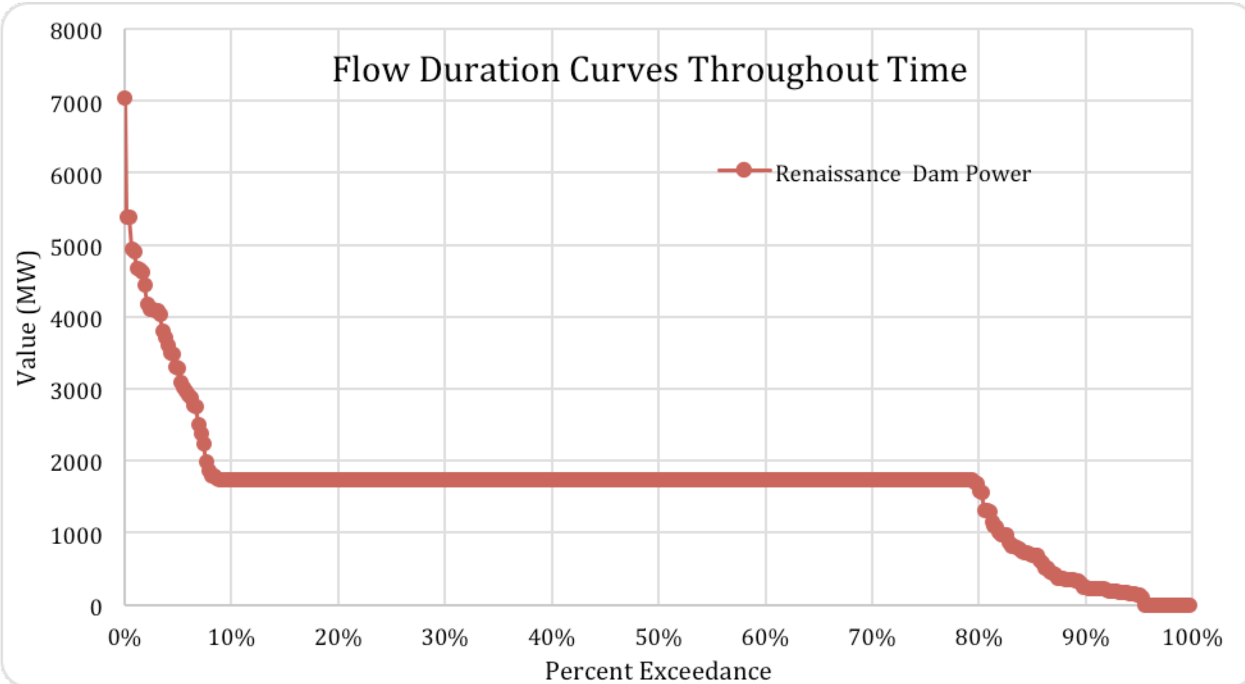


Figure 17 Reliability of the power generated at GERD

Energy generated at Rosaries dam

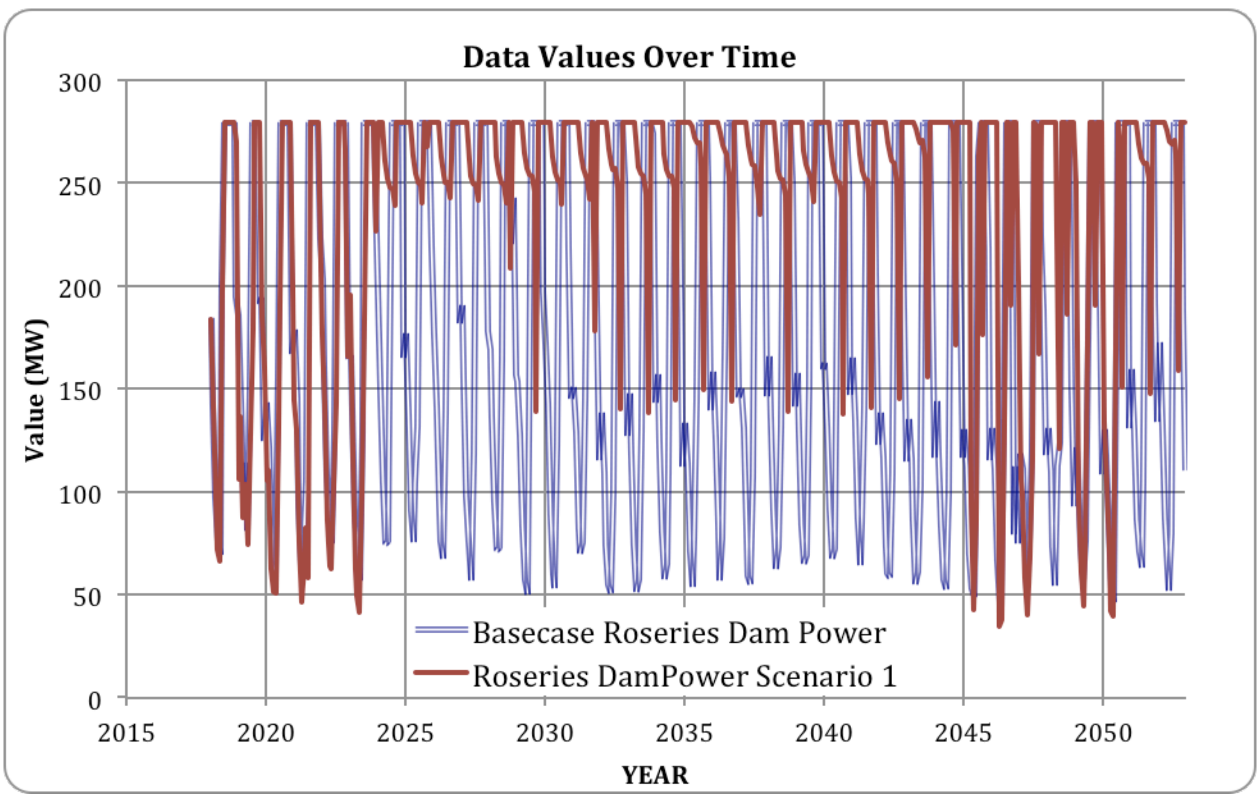


Figure 18 Comparison of Base case and Scenario 1 of Rosaries Power Generation

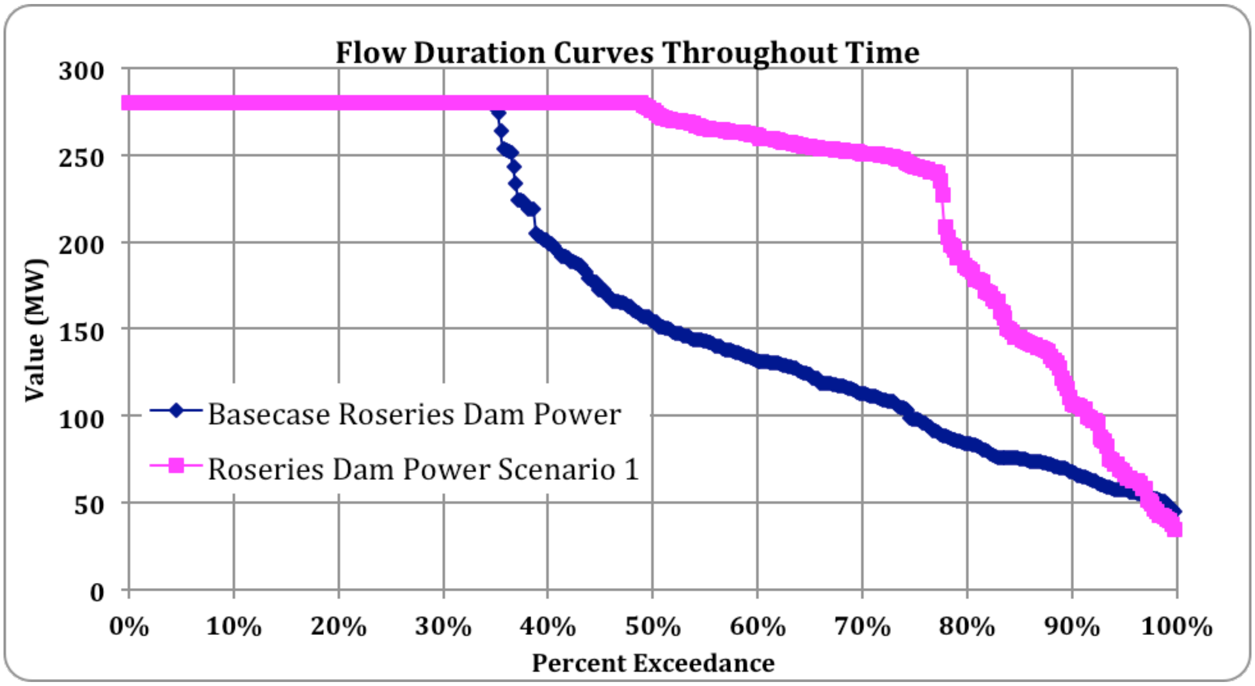
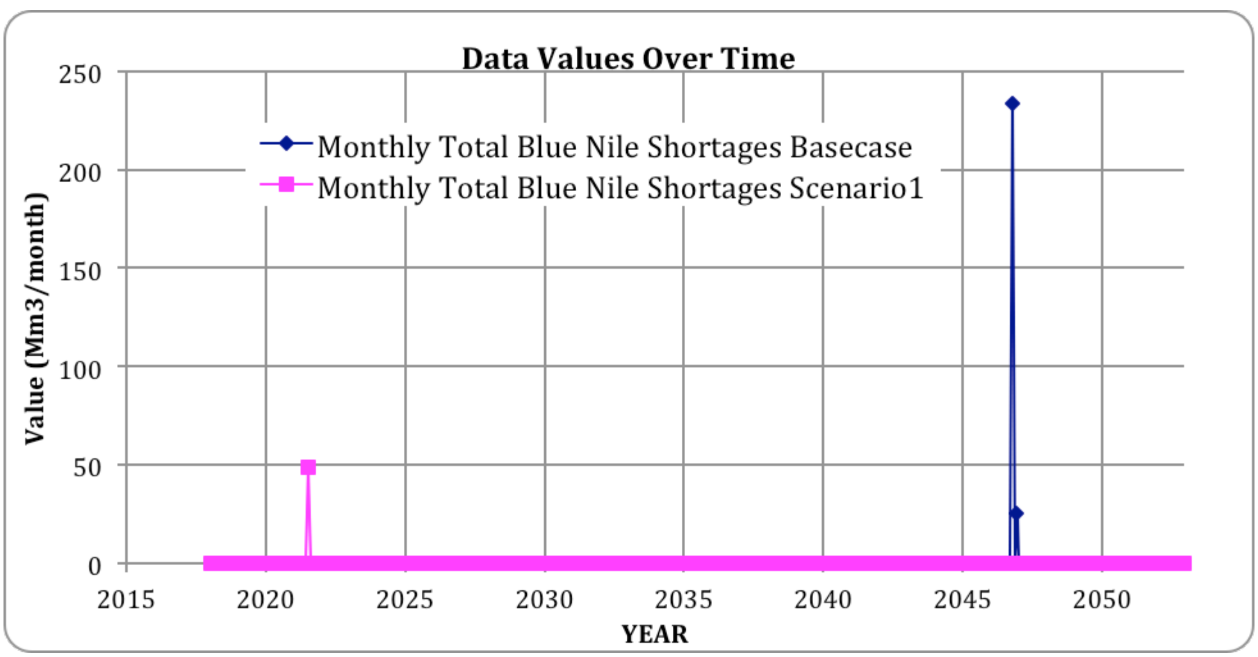
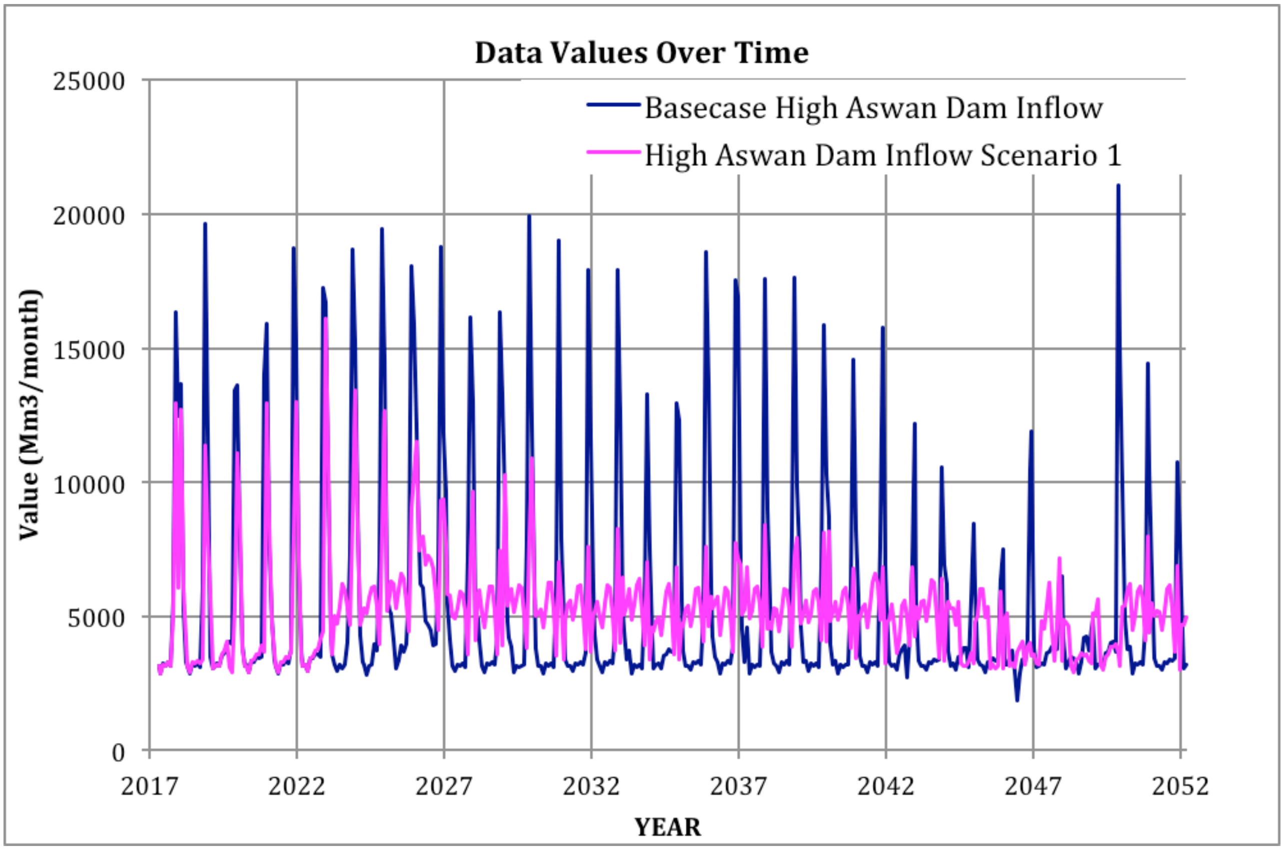


Figure 19 Reliability of the power generated at Rosaries Dam

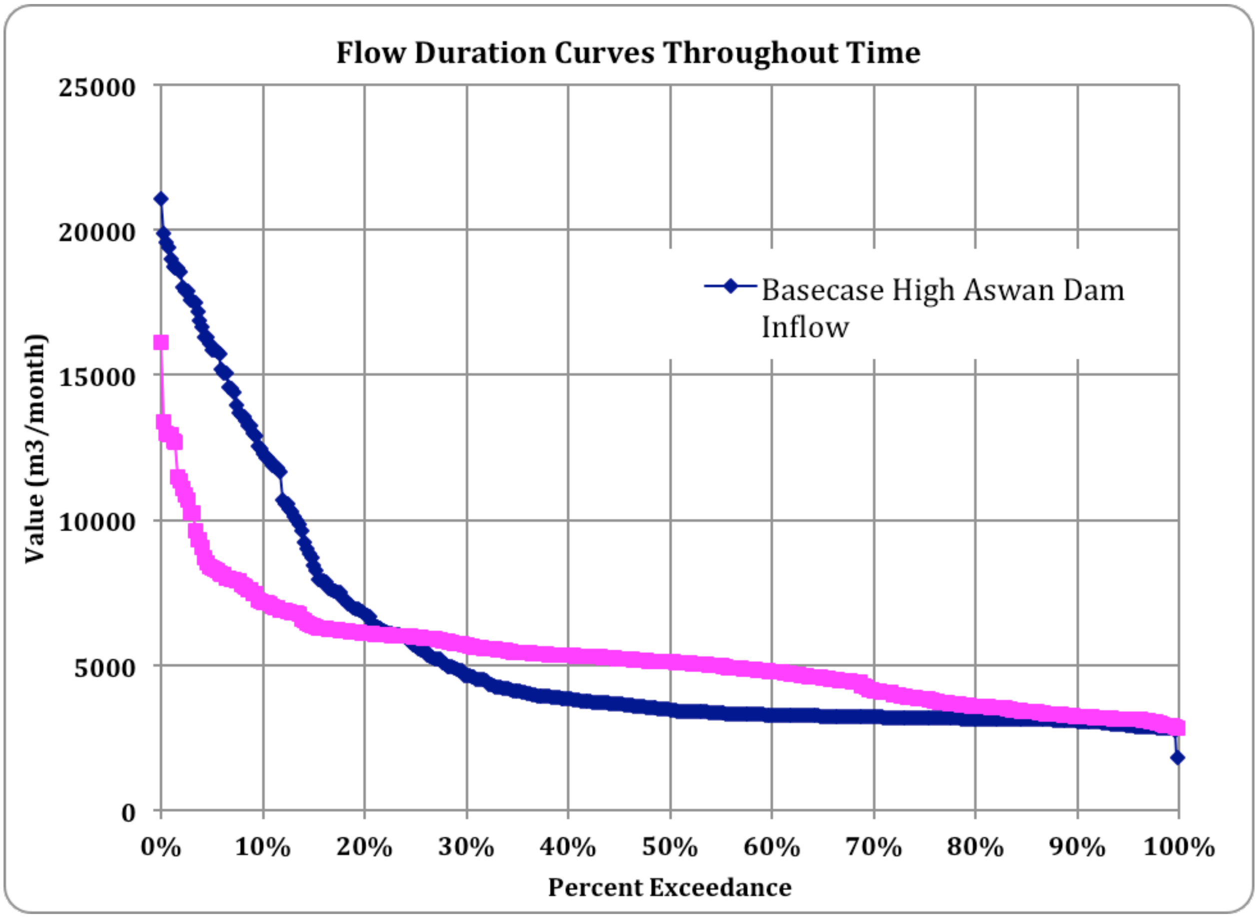
Agriculture System in Sudan (irrigated):



Water flowing to Egypt:



The above set of figures shows how the new dam will impact generation of power in Sudan (e.g Rosaries) , agriculture in Sudan, and the flow of water to Egypt.



Flow Duration Curves Throughout Time
25000
20000
15000
10000
5000
0
Value (m3/month)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent Exceedance
Basecase High Aswan Dam Inflow

4.0 Evolution of institutions in the EN and historical coping strategies:

Thousands of years ago, the people living along the banks of the Nile migrated away from the river and then back, as the Sahara desert expanded (8000 BCE) and then contracted (5000 BCE) in response to large-scale hydrologic variability associated with north-south shifts of the rainfall zones. This latest migration coincided with the emergence of the Pharaonic civilization. So, human migration was and still one of the main mechanisms through which human population in the Nile basin copes with large-scale variability in climate.

The drought of 1888 and the drought of 1914 are good examples for significant historical variability in the hydrology of the Nile basin. The two years were associated with major El Nino events. While the 1888 drought resulted in a major famine, the 1914 drought did not leave a similar impact. The reason for this difference is in how society responded to the natural hazard, reflecting different levels of vulnerability in the two episodes. In 1888, the society in Sudan was quite vulnerable due to political instability, internal revolts, and foreign wars. In contrast, 1914 was a year with stable social and political conditions. This contrast highlights the fact that risk from climate change or climate variability depends on both the severity of natural hazard, and the level of societal vulnerability. Institutions are the main organs of society specialized in planning and management of how society would cope with any natural hazards that may result from climate variability and change.

In the more recent past, specialized institutions were developed in the countries of the Eastern Nile basin to plan and manage the response of society to variability in climate and hydrology. In particular, meteorological departments and ministries of water resources in the countries of the Eastern Nile represent the institutions in charge of this vital role on behalf of the respective governments. One notable example is the Egyptian institution, Nile Forecasting Center, located in Cairo. This center produces forecasts of the flow into lake Nasir by utilizing measurements of rainfall over the Ethiopian plateau and upstream river flow. Similar specialized groups exist n Sudan and Ethiopia but with significantly smaller technical capacity. Similarly, meteorological agencies in the three countries issue routinely rainfall forecasts for their respective countries, with different lead times.

In recent years, under leadership of Dr. Yosif Ibrahim, ENTRO started producing annual forecasts of hydrologic and climatic conditions in the Nile basin, in the form of the Eastern Nile Flood Monitoring Bulletin, and the Eastern Nile Seasonal Forecasts. These new regional flood forecasting products represent a significant step forward for two main reasons. First, the regional nature of these products insures that information about hydrologic variability including floods and droughts is shared between all the countries.

This approach is much more efficient than duplication of efforts in the different countries, specially given the different technical capacity levels that are available for the three countries. Second, the new regional forecasts utilize information about the El Nino forecasts to extend the lead-time of the Nile forecasts. This is a critical step forward, since in large rivers like the Nile, forecasts of floods and droughts are needed with long enough lead-time such that management decisions can be effective in adjusting the operations of reservoirs in response to hydrologic variability.

5.0 Trends in infrastructure development & management:

The following table documents the results of the Questionnaire distributed to experts from the Eastern Nile countries. The table summarizes the answer to question D.
It describes strategies to cope with historical variability in the past and likely changes in the future. The same table summarizes the main trends in infrastructure development in the past, recent history, and the future.

Strategies to Cope with Historical Variability	Trends in Infrastructure Development
PAST 1. Countries developed flood early warning systems; 2. No strategy for dealing with droughts 3. Reaction to floods and droughts is of short term nature; no long term strategy	There were slow changes in the system during the 20^{th} century
FUTURE 1. Strategies are slowly evolving, or not at all evolving in response to the challenge of climate change. 2. Climate change is sometimes used as an excuse for inadequate institutional response to seasonal floods and droughts.	1. Renaissance Project 2. Rosaries Dam expansion (recently completed)

Appendix

<u>Questionnaire</u>

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

(C) STRATEGIES TO COPE WITH HISTORICAL VARIABILITY:

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)?.

……………………………………………………………………………………….

……………………………………………………………………………………….

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

……………………………………………………………………………………………

(D) TRENDS IN INFRASTRUCTURE DEVELOPMENT:

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?

………………………………………………………………………………………………