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Eastern Nile Basin Water System Simulation Using Hec-ResSim Model

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EASTERN NILE BASIN WATER SYSTEM SIMULATION USING HEC-RESSIM MODEL

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ABSTRUCT

Eastern Nile Basin water resource related issues are complex. Addressing water resources related economic, social and technical issues requires specialized tools. These tools should, among other water resource investments and evaluate them in a regional context. That is why Eastern Nile Technical Regional Office(ENTRO) initiated the Eastern Nile Planning Model Project (ENPM). ENPM strives to develop various models that can be used to fill the knowledge gap, cross check analyses, support and address water resource development and management decisions. Hec-ResSim Model is one such model used to simulate the water system in the Eastern Nile Basin. It is public domain model that enable easy sharing knowledge and data among Eastern Nile Countries and researchers. The model has advanced features in operating goals defined by flexible on site and downstream control functions and multi-reservoir system constraints. The model is developed for the entire Eastern Nile Basin for Abbay –Blue Nile, Tekeze-Setit-Atbara, Baro-Akobo-Sobat and Main Nile Sub basins. The base line models is configured in such a way to represent the current infrastructure and known management practices and calibrated with historical hydrological regime. The model is calibrated and its performance is checked using Nash-Sutcliffe efficiency at key gauge stations selected from each of the sub basin and the performance gives an accuracy of 0.85 and more for most of the key stations. Investment studies undertaken in the basin along with different selective development scenarios including proposed dams, irrigation schemes and cascade options for each sub basin have been simulated for the period of 1960 to 2002 These scenarios are analyzed by comparing the inflow, water level and energy production for existing dams under cascade options for Blue Nile and various proposed scenarios in respect to the effect on downstream water users.

1.0 INTRODUCTION

After decades of tension over the use of the waters of the Nile River, the countries began to work toward cooperative management of water and other natural resources for their mutual benefit. This evolving regional cooperation, which began in 1999, is under the auspices of the Nile Basin Initiative (NBI). Under the NBI, the riparian countries adopted a “Shared Vision,” the goal of which is "... to achieve sustainable social-economic development through the equitable utilization of, and benefit from, the common water resources."

This shared vision is supported by the following four specific objectives: (i) develop the water resources of the Nile Basin in a sustainable and equitable way to ensure prosperity, security, and peace for all its peoples; (ii) ensure efficient water management and the optimal use of the resources; (iii) ensure cooperation and joint action among the riparian countries, seeking win-win gains; and (iv) target poverty eradication and promote economic integration.

Under the NBI, the Eastern Nile countries - Ethiopia, Egypt, and Sudan - initiated in 2001 the Eastern Nile Subsidiary Action Program (ENSAP). ENSAP is an integrated investment-oriented regional multipurpose program aimed at deepening cooperation and generating tangible on-the-ground benefits for the riparian countries. The first set of investments under ENSAP approved by the Eastern Nile Council of Ministers (EN-COM) comprises the following seven projects: Watershed Management, Flood Preparedness and Early Warning, Eastern Nile Planning Model, Baro-Akobo Multi-purpose Water Resources Development, Ethiopia-Sudan Transmission Interconnection, Eastern Nile Power Trade Study, and Eastern Nile Irrigation and Drainage. To manage and coordinate the preparation of these and other projects, the ENCOM approved the establishment of the Eastern Nile Technical Regional Office (ENTRO) in 2001.

The Eastern Nile Planning Model (ENPM) and the development of Knowledge Management system are now the primary responsibility of the Water Resources Planning Unit. The objective of the ENPM is to avail to the three EN countries an improved decision support modeling framework to identify water-related investments and evaluate them in a regional context. The ENPM Project has three major components: Knowledge Base Development, Modeling System and Institutional capacity building. The ENPM modeling system includes a suite of simulation, optimization and multi-criteria analytical tools. The models are intended to help analyze critical Eastern Nile issues - e.g. relating to storage, hydropower investments, watershed management, irrigation, flood management, and overall Basin management. The multitude of tools allows examination of various technical, economic, environmental and social aspects in a water resources systems framework, evaluate alternative scenarios of the future, and improve development and management of the shared resource base to realize opportunities and reduce risks.

2.0 OBJECTIVE

The objective of this study is to simulating the water system in the basin and cumulative impact assessments of basin-wide water resources development like evaluate the effect of cascading of dams on the existing water system especially on downstream water users. The model will also serve as a basis to assess regional development options that can promote benefit sharing among the Eastern Nile countries to avoid the concept of water conflicts in the region.

3.0 EASTERN NILE SUB BASINS

The Eastern Nile basin is divided into four sub-basins: the Baro-Sobat-White Nile in the west, the Abbay-Blue Nile, the Tekeze-Atbara on the east and the Main Nile from Khartoum to the Nile delta. The Main Nile is the largest sub-basin of the ENB covering 44% of its total area while the Tekeze-Atbara-Setite is the smallest sub-basin covering 13% of the area.

3.1 The Abbay-Blue Nile Sub-basin

The Blue Nile (or Abbay as it is known in Ethiopia), with an area of over 310,000 km2 originates in the highlands of the Ethiopian plateau. It begins its long journey to the Main Nile from Laka Tana and through a deep gorge dropping from about 4000 masl to 400 masl on its journey to Khartoum.

The Blue Nile (Abbay) contributes most of the Eastern Nile waters. The 3.5 Bm³ that leaves Lake Tana at the headwaters of the Blue Nile is augmented by several major tributaries such as the Didessa, Dabus, Guder, Anger, and Beles to yield about 54 Bm³ total when the river flows into Sudan. The climate of the Abay-Blue Nile basin varies from humid to semiarid. Most precipitation occurs in the wet season (June through September), and the remaining precipitation occurs in the dry season (October through January or February) and in the mild season (February or March through May). Mean annual evaporation ranges from about 1,500mm (Fiche station (2,300 masl) in the highlands of the sub-basin) to more than 6,800mm around Khartoum, the mouth of the sub-basin. Flooding is a serious problem at the mouth of the basin such as Khartoum as well as in the upper course of the sub-basin.

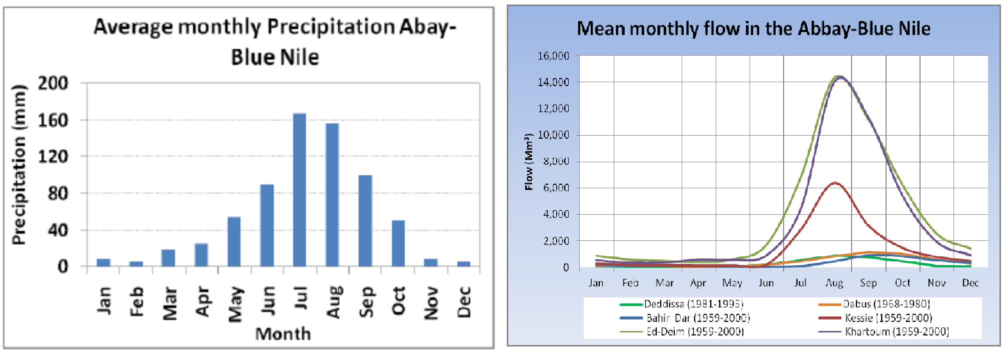
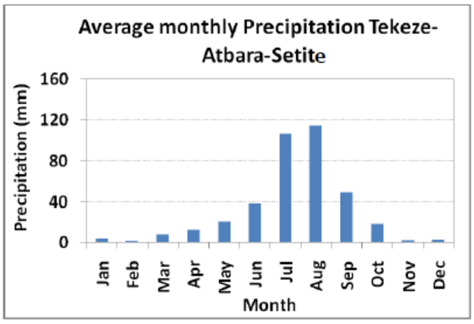


Figure 1. Seasonal distribution and hydrologic variability on the Abbay-Blue Nile.

3.2 The Tekeze-Setit-Atbara (TSA) Sub-basin

The TSA sub-basin (covering about 230,000 km2) consists of the Tekeze river (known as the Setit in Sudan), and its tributaries, the Goang (Atbara in Sudan) and Angereb, all of which originate in the north central highland plateau of Ethiopia. As the river makes its 1325 km journey, it falls from a height of about 3000 masl near its origin to about 500 masl when it joins the main Nile in Sudan, about 285 km downstream of Khartoum.

Water availability in the Tekeze-Setit-Atbara is erratic. The rainfall varies from 1000 mm near the source of the river to about 40 mm near its junction with the Main Nile. The flows are highly variable (compared to the Blue Nile and Baro-Akobo-Sobat sub-basins) especially in the crucial low flow months (see Figure 2). The main stem of the sub basin at El-Girba station (about 156000 km2) is observed to have mean annual inflow of 11.45 Bm³ (1980-2000).



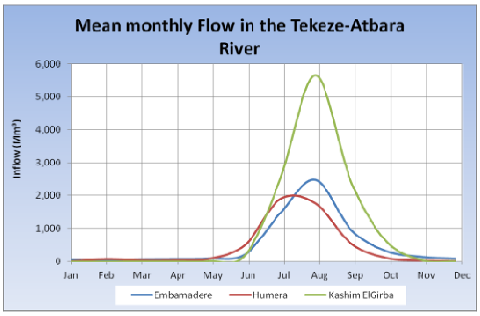
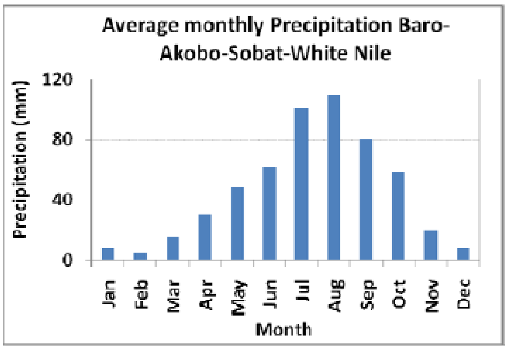


Figure 2. Seasonal distribution and hydrologic variability on the Tekeze Atbara Setite

3.3 The Baro-Akobo-Sobat (BAS) and White Nile Sub-basin

The BAS Sub Basin. Covering about 180,000 km2) consists of the Baro river (and its tributaries such as the Birbir) and the Akobo river (with its main tributary, the Pibor). After the confluence of the Baro and Akobo, the river is called Sobat in Sudan. The river makes its way from an altitude of over 3000 masl in the Ethiopian hills to about 400 masl when the Sobat crosses into Sudan on the way to its junction with the outflow from the Sudd wetlands that buffer the outflows from the Nile Equatorial Region. The resulting White Nile (with its basin covering about 280,000 km2) flows north to Khartoum where it joins the Blue Nile.

Water availability in the BAS.The Baro-Sobat-White Nile sub-basin within Ethiopia is well-watered. However, spatial variation of the mean annual rainfall is considerable due to the great range in elevation across the basin. Average annual precipitation ranges between 600 mm in the lowlands (less than 500 masl) and 3,000 mm in the highlands (over 2,000 masl). Average rainfall greater than 100 mm occurs from May to October. The highest rainfall occurs in June-September (ENTRO, 2006c).



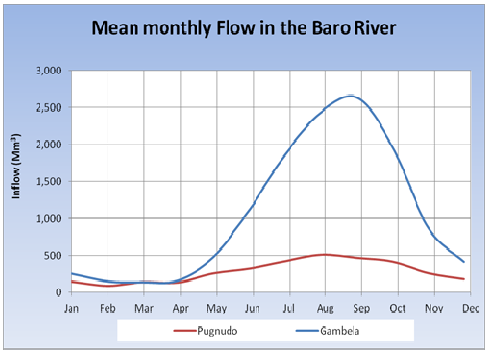


Figure 3. Seasonal distribution and hydrologic variability on the Baro –Akobo-Sobat-White Nile.

3.4 The Main Nile Sub-basin

The Main Nile sub basin is characterized with mild land slope. The total sub basin area, is estimated at 789,140 km2. Evaporation is observed to be considerably high. Lake evaporation at HAD is estimated at 2.6 m/year (Egypt OSI report Water Component, May, 2006). The Potential evapo-transpiration in the sub basin is estimated at 6.8 m (Khartoum station), 7.8 m

(Dongola station), 5.8 m (HAD station) and 1.8m (Alexandria) in the coastal line of the Mediterranean Sea.

The Main Nile Basin in particular is virtually known for its arid climate where moisture is almost non-existent. Mean annual rainfall at Khartoum is below 200mm, reduced to less than 20mm at Atbara, and almost less than 5mm at Dongola and the Aswan High Dam. At Cairo it is 25mm and increases to 200mm (Alexandria) in the coastal line of the Mediterranean Sea. Average runoff over the entire area of the delta in Egypt is estimated at 1bm3, which accounts for only 3% of the runoff reaching the delta through the Nile system (Water OSI Report of Egypt, May 2006). Mean annual rainfall of less than 50mm is experienced in more than 65% of the sub-basin and that above 100mm is experienced in only 17% of the sub-basin (ENTRO, 2006b). The average monthly rainfall of this basin with the available data is shown in Figure 4 where the maximum precipitation is observed in August.

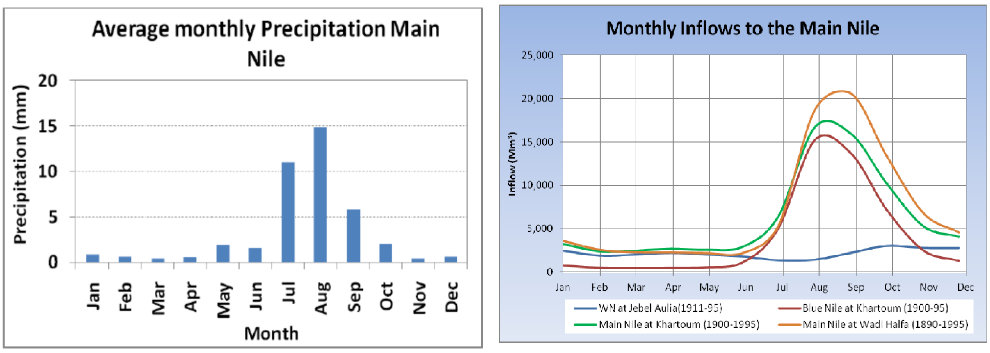


Figure 4. Seasonal distribution and hydrologic variability on the Main Nile

4.0 MODEL CONFIGURATION

This study uses reservoir simulation model, HEC-ResSim, as the successor to the well-known EC-5. Hec-ResSim allows the user simulate reservoir operations in complex basin as the eastern Nile where cascades of reservoir exist and proposed and the model also represents a significant advancement in the decision support tools available to water managers.

The model developed for the entire Eastern Nile Base including the four sub basins. During the model development ENTRO have made an effort to use the most updated data and capture most feasible proposed infrastructure structures and water demand in the basin. The model schematized for base case four existing reservoirs in the Blue Nile Sub Basin. Two reservoirs in the Ethiopian highlands are Lake Tana and Fincha reservoirs, and the other two reservoirs named as Roseires and Sennar are located in the Sudan u/s of the Khartoum station. The Grand Renaissance Dam (GERD) in Ethiopia and heightened Roseries dam in Sudan is considered in all scenarios since it is already under construction and already heightened respectively. Current irrigation practice in the upper part of this sub basin is largely limited to small scale level developments. While in the downstream reach, including the Gezira/Managil project six large scale projects with a total estimated area of 1,110,926 ha is under operation. Two projects (Sennar and Guneed sugar schemes) are sugar producing projects owned by the Sudan government. The Gezira/Managil scheme which accounts nearly 90% of irrigated agriculture development in the sub basin along with the other three projects (El Suki -75,375 ha; Rahad-153,756 ha; and Guneed extension-13,875 ha) are implemented as proposed irrigation demands.

The Tekeze Setit Atbara Subbasin doesn't have a lot of water infrastructure Khasham-el-Girba Dam, a 1.3 Bm³ reservoir built in 1964 in Sudan. It has an installed power capacity of 12.5 MW and feeds the 150,000 ha New Halfa Scheme and a 22,500 ha New Halfa sugar scheme. Recently, another hydropower dam (the 400 MW Tekeze or TK5) and Merowe dam in Sudan has been commissioned in Ethiopia on the main reach of the Tekeze River and Sudan respectively. There are also a number of small dams in the basin, primarily built for watershed management purposes which are not considered in this study.

Jabel Aulia Reservoir is located at the mouth of the White Nile. It was built in 1937 with a storage capacity of 3.5 Bm³. Upstream of the Jebel Aulia reservoir, pump abstractions for irrigation is currently under operation. Assalaya & Kenana sugar schemes with a total command area of 80,144 ha have been considered as water abstraction points. Going to downstream of the basin the High Aswan dam is considered with the current water abstraction for irrigation and power generation. The High Aswan dam operation rule captures the current operation rule which depend on the downstream irrigation demand and inflow to the dam.

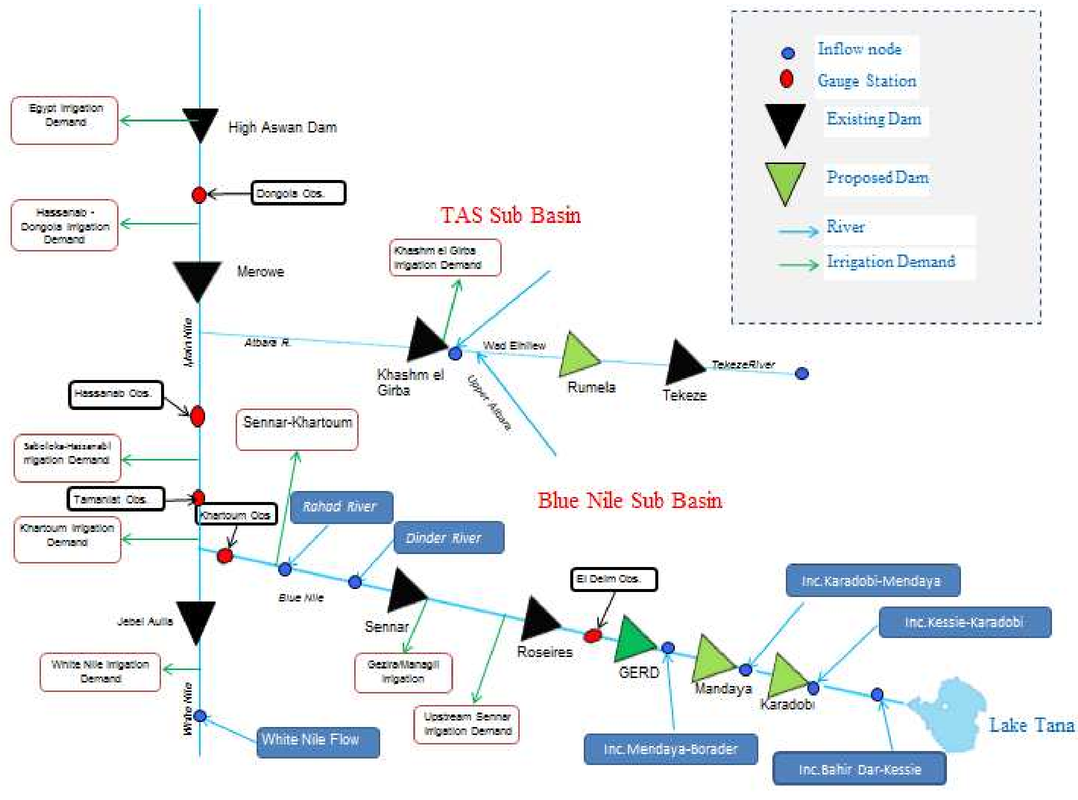


Figure 5. Eastern Nile Basin Schematic

The major input data prepared were stream flow data at various locations like inflow to reservoirs and incremental flows. The model is run under different hydrological conditions using the index-sequential method to replicate historical inflow pattern at different periods of time and a time series of data from 1960 to 2002 is used. A monthly water demand is considered at different existing and proposed irrigation, water supply, industrial and hydropower demand sites. Reservoir nodes require physical characteristics, operation rules and hydropower generation details. The model uses current operation rule for existing reservoirs and proposed filling strategies for the proposed dams.

The performance of the model is checked after calibration using observed flows and water levels at El Diem, Khartoum, Hassanab, Tamaniat, Embameder , Kilo3 and Donogla gauge stations and at Lake Tana and Roseries Dam for water levels. The smallest Nash-Sutcliffe efficiency obtained is 0.85 which taken as a reasonable result taking into consideration the size of the basin and the fact that the model only consider large infrastructures.

For simulation of future situation the model is run using different scenarios with combination of feasible projects in the basin. In the Blue Nile cascades of dams are used to develop scenarios using the Joint Mullti Purposed (JMP) study which was one of ENTRO previous study which provide a list of dams in the Blue Nile and their cascade options. The scenarios were developed using the anticipated water resource development as shown in Table 1.

Table 1. Scenario Definition

Scenario	Description
Scenario 0	Base Case
Scenario 1	GERD
Scenario 2	GERD (to assess dam filling options)
Scenario 3	GERD+ Karadobi
Scenario 4	GERD+ Karadobi+ Mandaya
Scenario 5	GERD+ Karadobi+ Mandaya +Beko Abo Low
Scenario 6	GERD+ Beko Abo
Scenario 7	GERD+ Beko Abo+ Mandaya
Scenario 8	GERD+ Rumela

5.0 RESULT AND CONCLUSION

The Hec-ResSim Model developed is used to run the above scenarios and evaluated according to availability of water in the basin at key location and power generating capacity on basin level with hydrological fluctuation pattern. These practices are presumed to achieve multiple objectives such as meeting direct and downstream demands, providing a reliable source of power generation, achieving target elevations, making target releases, and meeting environmental criteria. The calibration of the model was considered successful, although the lack of historical depletion data posed a significant limitation. Losses in reaches, lags in reaches and evaporation rates were adjusted to allow the model to match historical data.

The model was configured to allow the user to invoke essentially any combination management actions in the basin. The cascade options were simulated to assess the impact on downstream countries and existing infrastructures the has given an insight into the basin water resource potential and can be used as starting point to prioritized water related investments in the basin. The model can support the decision making process by giving quantitative result in considering management action. Therefore we can use this study investigating investment opportunity to maximize the benefit sharing between Eastern Nile Countries without significant effect on the water resource of the basin.

More importantly, the model was developed in a manner that would allow modifications to be readily made to the model including adding new infrastructure, modifying operational rules, considering climate change or improving input data. Since it is public domain it can easily be used by any user so that its application expands to stakeholders, and additional data and information about the basin is likely to be availed through new perspectives. Considering climate change as one of the scenario is recommended for future study.

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