International Journal of Nile Basin (IJNB)
Energy, Water, Environment & Economic
Volume 2; Issue 4;
August 2015, Page 1-11

The Next Task: Hydrologic Simulation of the Grand Ethiopian Renaissance Dam

Alemayehu W. Gebriel[1], PhD, PE

wg.alem@prodigy.net

Summary

The Agreement on the Declaration of Principles (DoP) on the Grand Ethiopian Renaissance Dam **(**GERD) was signed by the respective heads of state for Ethiopia, Egypt, and the Sudan on March 23, 2015 in Khartoum, Sudan. Performing hydrologic simulations of the GERD using appropriate modeling system is one of the main tasks that need to be completed in order to implement the principles stated in the DoP for utilization of the shared water resource of the Nile. A selection of reliable hydrologic modeling system is critical to answer the many issues that have not been addressed so far. The main purpose of this article is to review some of the modeling work done on GERD and available hydrologic modeling systems and their capabilities. The next important task will be to select appropriate hydrologic modeling system and perform hydrologic simulations of GERD. The technical results from the hydrologic simulation of the river basin help for negotiations to reach consensus in order to realize the spirit of cooperation and the principle of equitable and reasonable utilization of the Nile River as stated in the DoP. In addition, the results of the hydrologic simulations could be used in formulating reservoir operations policies and management of the GERD.

Background

The Nile River system consists of two distinct basins, the White Nile and the Blue Nile (also called Abbay in Ethiopia). The White Nile has its origins in the hills of Burundi and Rwanda, while the Blue Nile starts in the Ethiopian highlands of Lake Tana. The Nile is the longest river in the world, flowing for more than 6,650 kilometers (km) from its origins in Burundi and Rwanda to the Mediterranean Sea. It has a basin area of more than 3 million square km, extending over 11 countries that share the river, and covering one-tenth of the African continent [1] (Gebre Tsadik, 2003). It has been estimated that the Ethiopian Highlands contribute 86% of the Nile's flow. The Blue Nile with its various tributaries contributes 70 % of the flow to the Nile River. Even though, Ethiopia is the major contributor to the Nile flow, it has not utilized the Blue Nile water resource to improve the living standards of its citizens. For instance, figures from the World Bank show only 17% of the

---

[1] Dr Alemayehu Gebriel is a Water Resources Professional and Professional Engineer in the State of Texas, USA with experience over 20 years and head of EIPSA Agriculture and Environment Department.

Ethiopian population has access to electricity and only 0.65% of the Nile water has been utilized by Ethiopia.

Ethiopia is building the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile. The project is self-financed by the Ethiopian people and estimated to cost $5 Billion. The GERD is located approximately 750 km northwest of Addis Ababa, at a place called Guba in the northwestern part of Ethiopia 45 km from the Sudan border. The dam work mainly consists of a Roller Compacted Concrete (RCC) dam, two powerhouses, a gated spillway and a rock-fill saddle dam. The main dam will have a length of 1,780 meters (m) and a height of 145 m. The reservoir will have 74 billion cubic meters (BCM) of storage capacity and about 60 BCM live storage.

The two powerhouses will be at the downstream of the main dam: one on the right bank and the other on the left bank. They will accommodate 10 and 5 Francis Turbine Units respectively, with a total installed generating capacity of 6,000 megawatts (MW). The reservoir will have three spillways, designed for a probable maximum flood (PMF) of 19,370 cubic meters per second (m^3/s).

The project is currently about 42% percent complete and expected to be fully complete in 2018. The GERD, when completed, will generate 6,000 MW of electricity for export and domestic use. Egypt and Sudan have raised some concerns. Their main issue is that the available flows downstream of the dam will be reduced; however, hydrologic simulations to determine the impact of the project have not been performed.

The Agreement on Declaration of Principles on GERD

The DoP was signed on March 23, 2015 on GERD in Khartoum, Sudan. After the signing of the DoP by Ethiopia, Egypt, and the Sudan, significant discussions were presented in various sources [2, 3, 4, 5, 6, 7 and 8]. Several comments and analyses have been presented about the DoP since the signing of the principles by various media outlets and Ethiopian scholars. The analyses presented by Ethiopian scholars differ from one extreme to another. One of the articles declared the signing of DoP as “a sale of Ethiopia’s interest” while several others called it “a step in the right direction.” The main purpose of this article is to present a discussion on the next step that should be taken to implement the principles stated in the DoP for utilization of the shared water resource. The focus of this article is not to re-analyze the analyses rather to present the next tasks that need to be accomplished to build on the spirit of cooperation stated in the DoP. A brief synopsis about the DoP is presented below

The DoP contained 10 Articles and a brief description of each is presented below:

- **Article I**: Principles and Cooperation
- **Article II**: Principle of Development, Regional Integration and Sustainability – this article is specific to GERD.
- **Article III**: Principle Not to Cause Significant Harm
- **Article IV**: Principle of Equitable and Reasonable Utilization
- **Article V**: Principle to Cooperate on the First Filling and Operation of the Dam – this article is specific to GERD
- **Article VI**: Principle of Confidence Building – this article is specific to GERD
- **Article VII**: Principle of Exchange of Information and Data
- **Article VIII**: Principle of Dam Safety- this article is specific to the GERD
- **Article IX**: Principle of Sovereignty and Territorial Integrity
- **Article X**: Principle of Peaceful Settlement of Dispute

Most of the Articles contained in the DoP are similar to the Nile Basin Cooperative Framework Agreements (CFA) and a few are exactly the same (word-for-word) such as Article III – *Principle Not to Cause Significant Harm*, and Article IV *Principle of Equitable and Reasonable Utilization*. Most of the Articles are also similar to the 1997 United Nations Convention on the Non-Navigational Uses of International Watercourses. There are articles added specifically for the GERD such as Article II, Article V, and Article VI. Thus, the Articles contained in the DoP have used internationally accepted language and principles used in Non-Navigational Uses of International Water.

Nile Basin Cooperative Framework Agreements

The CFA is the result of serious negotiations between the Nile Basin Countries. The Nile Basin encompasses 11 countries: Ethiopia, Sudan, Egypt, South Sudan, Kenya, Uganda, Tanzania, Burundi, Rwanda, Eretria, and Democratic Republic of Congo. After a series of meetings to utilize the Nile water, a Nile Bain Initiative (NBI) was officially established by the Nile Basin states in 1999 [9].

The NBI is established as an intergovernmental organization, and has been viewed as a transitional arrangement to foster cooperation and sustainable development of the Nile River for the benefit of the inhabitants of those countries. The CFA is also referred to as the "Entebbe Agreement" after the Ugandan city which hosted its signing ceremony in May 2010. Kenya, Tanzania, Rwanda, Uganda, and Ethiopia have signed the agreement which has been ratified by their respective parliaments. Burundi later signed the agreement in February 2011. South Sudan has declared its support to the Entebbe Agreement but the current armed conflict has obstructed further action. Sudan and Egypt have not signed the agreement and have abstained from most of the negotiations. The two countries, Egypt and Sudan, have insisted that their existing uses and rights referred to in the Nile Water Agreement of 1959 which divides the Nile water between them (55.5 billion cubic meters for Egypt and 18.5 billion cubic meters for the Sudan) is not subject to negotiation. The other member states reject this matter [10].

The DoP signed between Egypt, Sudan, and Ethiopia is a set of principles; it is not binding, and does not determine any one country's share of the water. By signing the DoP, Egypt and Sudan have accepted the "*The Principle of Equitable and Reasonable Utilization"* which is a big departure from claiming the historical-use argument and insisting that the agreement of the 1959 water share signed by Sudan and Egypt be respected. The 1959 agreement (which Ethiopia is not a part of) gave all the water to Egypt and Sudan while Ethiopia got nothing. By signing the DoP, Sudan and Egypt accepted "*The Principle of Equitable and Reasonable Utilization"*; now, will they sign the CFA? The two countries (Sudan and Egypt) need to take the next step and sign the CFA and come to the negotiating table with the other Nile Basin countries to utilize the shared resources in equitable manner.

The Next Task: Hydrologic Simulation of the GERD

On April 9, 2015; Ethiopia, Egypt, and the Sudan announced that the three countries have agreed on the selection of two Consultants to provide a study recommended by the International Panel of Experts [11]. The names of firms have not yet been officially released. The scope of work details are not formulated, and at the printing of this Article are not disclosed. However, several news sources have indicated that the scope of the study includes hydrologic simulations to determine the filling durations of the GERD reservoir and downstream release amounts, and to determine the socioeconomic impacts of the GERD to the downstream riparian countries, Egypt and Sudan. A few articles have already appeared at international conferences and in publications about filling scenarios for the reservoir of the GERD. Some of the articles also presented discussions on reservoir operation policies.

One of the challenges of hydrologic studies is obtaining reliable and long-term stream flow data at the proper location in the river basin. To give the reader a broad understanding, a few of the published articles available in the public domain are reviewed below.

Ying et al, 2015 [13] used a variations of the water balance model (WatBal). The model generates monthly stream flows from inputs of monthly precipitation, daily mean temperature, and temperature range. This method uses an indirect method by generating synthetic stream flow data. The authors attempted to calibrate the flow generated from the model at downstream locations where measured stream gage data is available. All the locations used for calibrations are in the Sudan and Egypt. One of the locations in Sudan is the Roseires Dam, a second location is the confluence with the White Nile, and a third location is in Egypt just upstream of Lake Nasser. Based on the calibration, the paper presented some results that take into account climate change and predicted stream flow from 1961 to 1982 at the selected calibration locations. After generating the required input data, the GERD performance was assessed for the period of 2011 to 2060 (i.e., from filling of the dam to the estimated economic life of the dam). The hydrologic simulation utilized in the study includes the stream flow from the Blue Nile, the White Nile, and the Atbara (Tekeze - as it is known in Ethiopia). The simulation evaluated various filling policies and discussed potential impacts of climate change. The paper concluded, for example, impounding 10% of the monthly stream flow behind the GERD produces 6% average reduction, while impounding 25% of the monthly stream flow produces 14% reduction, in stream flow entering Lake Nasser during the first 5 years. Considering climate change, the reduction of stream flow at the downstream locations varies from -27.8% at the highest filling scenario with the highest reduction (minus 20%) in precipitation amounts to 2.4 % at the lowest filling scenario with the highest increase in precipitation (20%) trends.

The results presented in the paper are within the margin of error of most hydrologic models. Considering error propagation in generating stream flow data indirectly from several variables, and applying other computations which inherently produce errors; the error in the methodology may be ever larger and a confidence interval of ±25% is not unreasonable. The analyses assumed the status-quos in water share distribution between the three countries.

Asegdew and Semu, 2014 [14] evaluated the impact of the GERD on the performance of the High Aswan Dam (HAD). The authors utilized the Danish Hydraulic Institute (DHI) MIKE Basin software. The input data for the simulation were stream measurements, taking into consideration the irrigation demand in the Sudan. Monthly net evaporations, reservoir data of the GERD, and water use data (mainly irrigation water demand) were also considered. The results of the analyses indicated that the GERD will reach its operating capacity within 3 years after commencing impoundment. Within 9 years it could reach the full storage capacity of the reservoir at elevation 640 m. The simulation results indicated that during the filling period the downstream outflow will be more uniform on the order of 4,000 m^3 per month. This amount is more than the observed monthly average flow during the months of January through July [13].

Abdelkader and Mohamed, 2015 [15] attempted to evaluate the impact of the GERD on downstream countries in case of the unfortunate situation of dam failure. The authors used a steady-state HEC-RAS model to analyze the impact. The HEC-RAS steady-state model is not an appropriate tool to analyze dam failure. Since the authors did not use the proper tool the results and the discussion presented in the paper does not weigh much credit. The failure assumption in the paper considered the GERD like a picket fence that could buckle under the weight of water behind the dam. From the report released about the design of the dam, this assumption is flawed.

There are software packages that are designed to perform dam break analyses. These software packages include the unsteady state component of the HEC-RAS model and the US Weather service software package DAMBRK, to mention a few [16].

The dam break analyses software is used to develop the outflow hydrograph from a dam and hydraulically route the flood through the downstream valley. The software utilizes the unsteady flow routing and determines the inundation extent and depth. In producing the dam-break flood forecast, the model first computes the peak outflow at the dam; this computation is based on the reservoir size, the size of the breach, and the length of time it takes the breach to form. The computed flood-wave and channel properties are used in conjunction with peak-flow routing curves to determine how the peak flow will be attenuated as it moves downstream. Based on this predicted flood-wave reduction, the model computes the peak flows at specified cross sections along the downstream valley. The dam breach scenario is user defined based on some historical dam breach data. This kind of analyses is used for preparing an emergency action plan and to understand the inundation extent. For example, the USA dam owners and operators are required to perform dam breach analyses and prepare an "*Emergency Action Plan*." Some form of dam breach analyses or analyses of emergency flow releases from the reservoir of the GERD is needed and should be performed using appropriate software packages, with the correct input data, and breach assumptions.

Considerations in Hydrologic Simulations

Conducting a hydrologic simulation analysis is a standard procedure in determining filling duration and downstream releases. The main components in the analysis and input data are: appropriate program or software package; input data, such as inflow to the reservoir; physical parameters of the reservoir, such as storage-elevation data; and outflow structures or release amount. Other climatic data, such as evapotranspiration and channel loss in the stream bed, are also required.

The hydrologic simulation typically is carried out to cover a range of climatic conditions: dry year, wet year, and median year. The simulations are carried out on a monthly time step for several years. The model accounts for the inflow into the reservoirs, the storage in the reservoir, downstream releases, evaporation, and stream bed losses. The releases could be due to power generation after the flow operates the turbines [12] and additional release because of excess storage or for downstream environmental needs.

Model Selection for Reservoir Simulation

To support river basin management and operation decisions, a number of generalized and basin specific models have been developed and applied for a number of years [17]. In selecting a model the following are useful guidelines:

- Select a computer modeling system designed for application to a range of concerns dealing with river basin systems of various configurations and locations, rather than being site specific and customized for a particular system.

- Select a model that is user orientated, meaning modeling systems that are designed for use by professional practitioners (model users) other than the original model developers.
- Select a modeling system that is thoroughly tested and well documented.
- Select a modeling system that can perform the computational time step to meet the objectives of the analysis. For example, flood events occurring over a few days may require an interval of an hour or less. On the other hand, water supply capabilities may be modeled with a monthly time step. Several decades that encompass the full rage of fluctuating wet and dry periods including extended droughts periods also need to be modeled.
- Select a modeling system that accommodates stream flow as input data generated outside of the modeling system and/or a system that generates stream flows from precipitation-runoff processes. Generating stream flow from precipitation-runoff or other parameters require calibrations of the output with measured stream flow data.

Available Modeling Systems

A number of modeling systems have been developed and used for extended period of time. The terms *reservoir/river system*, *reservoir system*, *reservoir operation*, or *river basin management "model"*, or "*modeling system"* are used synonymously to refer to computer modeling systems that simulate the storage, flow, and diversion of water in a system of reservoirs and river reaches. Below is a representative list of current modeling system and their capabilities. These modeling systems have a record of successful applications by water management agencies and professionals in support of actual decision making.

1. **HEC-ResSim**: Reservoir System Simulation (HEC-ResSim) is a reservoir system simulation developed by U. S. Army Corp of Engineers (USACE) Hydrologic Engineering Center (HEC), Davis California. This model has been in development and use since 1996. It incorporates the predecessors modeling systems, HEC-3 and HEC-5, which were developed and used since the mid-1960s. HEC-ResSim will eventually replace the *HEC-5 and HEC-3* modeling systems. The software has been designed and tested primarily on Windows 2000 but runs on other versions of Windows as well. ResSim is comprised of a graphical user interface, a computational program to simulate reservoir operation, data management capabilities, and graphics and reporting features. Version 1.0 of HEC-ResSim was distributed for testing in 2001and the current version 3.1 was released in 2003. The model and documentation is available from the HEC website free of charge.
2. **RiverWare**™: Reservoir and River Operation (RiverWare) is a river and reservoir operating system. U.S. Bureau of Reclamation (USBR) and Tennessee Valley Authority (TVA) jointly

sponsored development of the RiverWare™ model at the University of Colorado. RiverWare™ development efforts started in the mid-1990s, and its predecessor models development date back to the mid-1980s. RiverWare™ is a proprietary software product. Information regarding obtaining the software, documentation, and training is available at the University of Colorado Bolder Advanced Decision Support for Water and Environmental Systems (CADSWES).

3. **MODSIM**: MODSIM is a Generalized River Basin Decision Support System and network flow model. MODSIM provides a general framework for modeling. The modeling system is designed to support long-term planning (monthly time step), medium-term management (weekly time step), and short-term operations (daily time step). Initial model development at Colorado State University dates back to the 1970s. Since 1992, the U.S. Bureau of Reclamation Pacific Northwest Region has sponsored continued model improvement efforts. The software and documentation may be downloaded free-of-charge from the Colorado State University web site.

4. **WRAP**: WRAP is the Water Rights Analysis Package (WRAP). Development of WRAP began at Texas A&M University in the mid-1980s. The development of the program is sponsored by a federal/state cooperative university research program administered by the U.S. Geological Survey (USGS) and the Texas Water Resources Institute (TWRI). The generalized simulation model was greatly expanded during 1997-2002 under the sponsorship of the Texas Commission on Environmental Quality (TCEQ) in conjunction with implementation of the Texas Water Availability Modeling (WAM) System. WRAP simulates management of the water resources of a river basin or multiple-basin region under a priority-based water allocation system. The public domain software and documentation may be downloaded from the Texas A&M University website.

There is also widely used proprietary software products developed and marketed by organizations that provide consulting services. A few of these models include: OASIS, ARSP, MIKE BASIN, RIBASIM, and WEAP and are described below. The model developers and other organizations have applied the models to reservoir/river systems located throughout the world.

5. **OASIS**: Operational Analysis and Simulation of Integrated Systems (OASIS) is developed and marketed by HydroLogics. The HydroLogics is a consulting firm specializing in water resources management with offices in Columbia, Maryland; Raleigh, North

Carolina; and Sacramento, California (http://www.hydrologics.net/). OASIS combination of a graphical user interface and OCL™ (Operation Control Language) enables data entry as a series of rules and constraints.

6. **ARSP**: The Acres Reservoir Simulation Program (ARSP) was developed by Acres International Corporation (http://www.acres.com/index.html) and is marketed and supported by BOSS International (http://www.bossintl.com/). Acres International is headquartered in Ontario, Canada. BOSS International has headquarters in Madison, Wisconsin. Both consulting engineering firms have multiple offices in various countries. The ARSP network flow programming model simulates multi-purpose, multi-reservoir systems. Operating policies are defined by prioritizing water demands. Monthly, weekly, daily, or hourly time steps may be used.
7. **MIKE BASIN:** MIKE BASIN is the reservoir/river system component of the Danish Hydraulic Institute (DHI) family of software. The DHI is an international consulting and research organization established in 1964 and located in Horsholm, Denmark (http://www.dhi.dk/). The DHI provides international consulting services in applying the models. MIKE BASIN runs within and is an extension to ArcView which is a geographical information system (GIS) software product available from ESRI (http://www.esri.com). MIKE BASIN integrates GIS capabilities with reservoir/river system modeling. Software features also facilitate interconnected use of Microsoft Excel with MIKE BASIN.
8. **RIBASIM**: River Basin Simulation (RIBASIM) is Delft Hydraulics (Delft) river basin planning and management model. Delft is an independent research institute and specialist consultancy in the Netherlands from which several generalized hydraulic simulation software packages are available (http://wldelft.nl). RIBASIN has been applied to a number of river basins throughout the world over the past 20 years. Hydrological water inputs at various locations in a river basin are linked with water users. A water balance for a reservoir/river/use system provides information on water availability and the source composition at all locations and time steps.
9. **WEAP**: The Water Evaluation and Planning (WEAP) System was developed and is distributed by the Stockholm Environmental Institute Boston Center at the Tellus Institute located in Boston, Massachusetts (http://www.weap21.org/). WEAP has been used in studies throughout the world conducted by United Nations agencies, the U.S. Agency for International Development, and other organizations. The software package is sold for commercial customers, with free or discounted licenses for not-for-profit organizations. WEAP is a reservoir/river/use system water balance accounting model that allocates water from surface and groundwater sources to different types of demands. The modeling

system is designed as a tool for maintaining water balance databases, generating water management scenarios, and performing policy analyses.

Conclusions and Next Step

As discussed in the preceding pages there are several modeling systems and software packages in use for river management and reservoirs operations. This list is not comprehensive and does not include other modeling systems that are in use for specific river basin and cited in various literatures. The above list includes a brief description of current modeling capabilities. These modeling systems have a record of successful applications by water management agencies and professionals in support of actual decision making.

The next step that should be taken to implement the principles stated in the DoP for utilization of the shared water resource of the GERD is to perform a hydrologic simulations using appropriate modeling system. In selecting a modeling system for the GERD studies, detailed evaluations of each modeling system should be carried out to make sure the selected system will meet the objective of the study before moving ahead full-steam on the analyses. In evaluating the modeling systems, the guidelines and modeling system capabilities presented here should prove useful. A dam breach analyses or emergency flow releases from the reservoir should also be performed with the correct input data, and breach assumptions.

References

1. Gebre Tsadik Degefu, 2003. The Nile: Historical, Legal, and Developmental Perspectives. Trafford Publishing, Victoria Canada.
2. Tecola Hagos. March 30, 2015. Declaration of Principles: Ethiopia got a loaf and a half. http://www.ethiomedia.com/101facts/4533
3. Fekade Shewakena. April 1, 2015. Some Notes on the Declaration by Ethiopia, Egypt and Sudan on the Use of the Nile. http://www.ethiomedia.com/101facts/4545
4. Minga Negash, Seid Hassan, Mammo Muchie and Abu Girma. Updated April 11, 2015. Regarding the Grand Ethiopian Renaissance Dam: Perspectives on the Declaration of Principles. http://www.ethiomedia.com/101facts/4577.html
5. Minga Negash, Seid Hassan, Mammo Muchie, Abu Girma, Aklog Birara and Getachew Begashaw. March 24, 2015. Update: Misplaced opposition to the GERD. http://www.ethiomedia.com/101facts/4519
6. Teshome Abebe. March 30, 2015. The Agreement on the Declaration of Principles: The GERD. http://www.ethiomedia.com/101facts/4539

7. EIPSA. April 4, 2015. EIPSA Press Release on Agreement on the Declaration of Principles (DoP) between Ethiopia, the Sudan and Egypt. http://www.eipsa1.com/cms/node/58
8. Salman Mohamed Ahmed Salman. March 30, 2015. Sudan Vision News Daily. How and why has the Ethiopian Strategy on the Renaissance Dam Succeeded? http://news.sudanvisiondaily.com/print.html?rsnpid=248051&copyType=1
9. Salman M.A. Salman. 2013. The Nile Basin Cooperative Framework Agreement: a peacefully unfolding African spring? Water International, 38:1, 17-29.
10. Mwangi S. Kimenyi and John Mukum Mbaku. April 28, 2015. The limits of the new "Nile Agreement". Brookings Institution.
11. Reuters Africa. Apr 10, 2015. Ethiopia, Egypt and Sudan pick two firms for Nile dam study. http://af.reuters.com/article/topNews/idAFKBN0N11EY20150410
12. Belachew Chekene Tesfa. 2013. Benefit of Grand Ethiopian Renaissance Dam Project (GERDP) for Sudan and Egypt. EIPSA Communicating Article: Volume 1; Issue1 http://www.eipsa1.com/cms/node/36
13. Ying Zhang, Paul Block, Michael Hammond, and Andrew King. 2015. Ethiopia's Grand Renaissance Dam: Implications for Downstream Riparian Countries. J. Water Resour. Plann. Manage.
14. Asegdew G. Mulat, Semu A. Moges**.** March 8 2014. Assessment of the Impact of the Grand Ethiopian Renaissance Dam on the Performance of the High Aswan Dam**.** Journal of Water Resource and Protection, 2014, 6, 583-598.
15. Abdelkader T. Ahmed and Mohamed Helmy Elsanabary. *12-14 March 2015* Hydrological and Environmental Impacts of Grand Ethiopian Renaissance Dam on the Nile River. *Eighteenth International Water Technology Conference, IWTC18.*
16. Tony L. Wahl. 2010. Dam Breach Modeling – An Overview of Analyses of Methods. 2nd Joint Federal Interagency Conference, Las Vegas, NV, June 27 - July 1, 2010.
17. Deepti Rani and Maria Madalena Moreira. 2010. Simulation–Optimization Modeling: A Survey and Potential Application in Reservoir Systems Operation Water Resour Manage. 24:1107–1138.