



ADDIS ABABA INSTITUTE OF TECHNOLOGY

**Effect of Great Ethiopian Renaissance Dam (GERD) on
downstream water uses of Eastern Nile River Basin**

By
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School of Graduate Studies
Addis Ababa Institute of Technology

**Effect of Great Ethiopian Renaissance Dam (GERD) on downstream water
uses of Eastern Nile River Basin**

**A thesis submitted to the school of graduate studies in partial fulfillment of the
requirement for the degree of Masters of Science in Civil Engineering**

(Major Hydraulic Engineering)

By

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I, the undersigned, certify that I have read and here by recommended for acceptance by the Addis Ababa University a dissertation entitled: “**Evaluation of the Great Ethiopian Renaissance dam (GERD) on downstream water uses of Eastern Nile River Basin** “ here by recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements of the degree of Masters of Science in Hydraulic Engineering.

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Dedication

The thesis is dedicated to my family, with a lot of love who poured me the spirit of hard work and encouraged me to finish this study. Right this moment I feel that you are smiling down

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Abstract

This study was conducted to analyze the water balance of the eastern Nile river basin and simulate the Evaluation of the Great Ethiopian Renaissance dam (GERD) on downstream water use. The simulation is based on different existing and under constructed water use sectors with different scenarios. A study was conducted on water allocation modeling of Awash River Basin, Ethiopia, using MODSIM, a river basin management decision support system (DSS) designed as a computer-aided tool for developing improved basin wide planning.

Eastern Nile river basin includes many reservoirs and swampy lands but in this study considering high Aswan dam, Merowe dam and Great Ethiopian renaissance dam. Four scenarios were set: Scenario I base line scenario with present withdrawal rate in the basin; Scenario II- normal flow impounding scenario during the filling period of Great Ethiopian renaissance dam the period of 2014.2019 ; Scenario III Scenario II Dry flow impounding scenario during the filling period of Great Ethiopian renaissance dam the period of 2014.2019 this is the rare case scenario under the impounding periods ; and Scenario IV-the long term future Scenarios considering Great Ethiopian Renaissance Dam. Analysis of flow records within the basin was done for a period of 1953–2003 for 47 years of monthly average stream flow, reservoir characteristics, and water use data of the basin. Simulation was conducted based on four scenarios. Consumptive and non-consumptive uses were considered in allocation modeling.

KEY POINTS: - Nile river basin, Blue Nile river basin, Great Ethiopian Renaissance dam (GERD), Merowe, High Aswan Dam (HAD), MODSIM, simulation, scenario

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List of Abbreviation

BCM	Billion cubic meters
C⁺⁺	Computer Programming Language
DSS	Decision Support System
EEPCo	Ethiopian Electric Power Corporations
FSL	Full Supply Level
GERD	Great Ethiopian Renaissance Dam
GIS	Geographic Information System
GUI	Graphical User Interface
GW	Giga Watt
GWH/Y	Giga Watt Hour per Year
HAD	High Aswan Dam
Km	Kilo Meter
M	Meter
m³/s	Cubic Meter per Second
m.a.s.l.	meter above Sea Level
MCM	Million Cubic Meters
mm	Millimeter
MOL	Minimum Operating Level
MS	Microsoft
MW	Mega watt
NBI	Nile Basin Initiative
NWL	Normal Water Level
RCC	Roller Compacted Concrete

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Water is a vital component of the Earth ecosystems, redistributed through natural cycles, contributing to climate control and the hydrologic cycle. As water flows, river ignores political boundaries, fluctuates in both space and time, and has multiple uses. Comprehensive integrated water resource planning and analysis of a river basin is then required for efficient water use in an optimal manner; the one which shows this is Nile river basin.

Nile river basin is one of the largest river basins in the world which is originates from the high land parts of Ethiopia, the central and southern parts of equatorial Africa passes through Sudan and Egypt and ends up in Mediterranean sea. Ethiopia contributes around 85% of the total Nile flow reaching Egypt. The equatorial Nile contributes about 15% of the flow

For a long period of time Nile provides almost all the fresh water for Egyptians. In addition to Egypt, Sudan also uses this water for multipurpose uses like irrigation, water supply, hydropower production, navigation, fisheries and other uses.

The upstream nations began to harness the Nile's waters to provide social security and economic prosperity for example, Ethiopia, recently emerged from a long period of civil war and embarked into a period of accelerated growth and economic development. In the past, Ethiopia did not use this source but now the government was started constructing Great Ethiopian Renaissance dam (GERD) that will use the Nile's flow to increase the hydropower production capacity.

1.2. Problem Statements

Like many river basin in the world, water resource in the Nile river basins are not fully developed and optimally allocated yet for the riparian's including Ethiopia. Now Ethiopia emerges a development from long period of civil wars and droughts. To succeed the development, hydro power s a vital components and also the country has a water potential to generate hydro powers. For this case Great Ethiopian Renaissance dam is constructing on the Blue Nile river basins.

Great Ethiopian Renaissance dam is anticipated to be the biggest hydroelectric power project in Africa with a planned installed capacity of 6,000 MW and 15,128 GW annual in Ethiopia . The project would satisfy the increasing domestic demand for electricity and provide reliable hydropower supply. For the sustained growth of the Ethiopian and the subsequent increased in demand for energy input is emphasizing the lack of power creation capacity in the country.

The ongoing construction of GERD becomes part of the eastern Nile basin water storage facility which alters the flow regime in the Nile river basin. Understanding the evaluation of the GERD in short and long term existence provides to sustainable management of the eastern Nile basin. Critical issues of the GERD include, evaluation of the dam during reservoirs filling period (impounding) establishing long term regularly harmonized operation policies and environmental issues due to the flow regime change. This research paper focuses on evaluation of the Great Ethiopian Renaissance dam on downstream water uses during the impounding phase and long term future scenarios.

1.3. Objectives

The main objective of this research is to evaluate the great Ethiopian renaissance dam, GERD on the downstream water uses of eastern Nile river basin. For this, basin-wide water resource using river basin management decision support system MODSIM models to evaluate the potential impacts of the newly constructed 6000 MW, GERD.

To achieve this following specific aims are envisaged for the study:

- Setup a modeling approach to simulate water use sectors in eastern Nile river basin based on number of functional power plants and under constructed GERD taking different scenarios using MODSIM model
- To compare the energy generation, evaporation losses, reservoir storage level, inflow-outflow at each scenarios based on the base line scenarios including the downstream irrigation demand of eastern Nile river basin.

1.4. Structure of the Thesis

Simulating a river basin including allocation and operation of water resource systems is described in this report and overview for this thesis is organized by seven chapters which are presented as follows:

Chapter 1 contains introduction, problem statement, objectives of the study, and organization of the thesis.

Chapter 2 gives a description of the study area and data, with the main characteristics of the eastern Nile river basin including the location, rainfall characteristics, and topography of basins. The chapter also discusses about the location, physical and operational characteristics of the existing hydropower plants and reservoirs.

Chapter 3 is the literature review and talks about methods how to manage water resources at a river basin scale and general river/reservoir simulation and operation techniques. The chapter reviews the available simulation models and describes the MODSIM model, its characteristics and applications.

Chapter 4 contains methodology and data configuration for the model. All the necessary data are identified, their availability checked and they are organized for analysis. Thus, physical and operational data, open water evaporation from the reservoirs surface and inflow to the

reservoir are analyzed, and finally how MODSIM model was built for eastern Nile river basin and how information was used and analyzed.

Chapter 5 contains results and discussions for each of the different scenarios

Chapter 6 contains conclusion and recommendations. Next to this reference and appendices sections are presented.

CHAPTER TWO

2. DESCRIPTION OF THE STUDY AREA AND DATA

2.1. Study Area

The Nile is generally regarded as the longest river in the world, and has a drainage area exceeding 3 million square kilometers, shared by eleven countries (Belachew, 2013). From south to north, the river flows over 35 degrees of latitude, traversing highly diverse landscapes and climatic zones as shown figure 2.1.

The main interest in this study is the eastern Nile basin which drains three main riparian countries namely Ethiopia, Sudan and Egypt consists of the major water resource development. The eastern Nile consists of the three main contributing tributaries to the main Nile i.e. the Blue Nile, the Atbara and the main Nile from Khartoum until the water reaches the delta of the Mediterranean Sea.

The existing and under construction water storage includes GERD, HAD and Merowe. Described as an order also the locations of this mega projects in the basin has been shown in figure 2.1.

➤ GERD

The Grand Ethiopian Renaissance dam (GERD) will become the largest dam and hydroelectric scheme in Africa. GERD is anticipated to be the biggest hydroelectric power project in Africa with a planned installed capacity of 6,000 MW and 15,128 GWH/ year. The project would satisfy the increasing domestic demand for electricity and provide reliable hydropower supply. The GERD project is located approximately 750 km northwest of Addis Ababa about 40 kilometers from Sudan's border on the Blue Nile River Guba in west of Ethiopia 45Km from Sudan. Guba is located at 11° 16' 0" North, 35° 17' 0" East. (Belachew, 2013)

The main dam which has a volume of approximately 10MCM, a crest length of 1780 meters and height of 145 meters, it is an RCC gravity dam, divided in three sections: right bank, central section and left bank. The central section will be used as a stepped spillway. This will

create a reservoir that covers, at full supply level, an area of 1,680 sq. km and hold a volume of 74 Billion cubic Meter (BCM) of water. (Belachew, 2013)

➤ **High Aswan Dam (HAD)**

The High Aswan Dam is a rock fill dam with a length of 3830 m of which 530m are within the river channel and the rest in the shape of two wings along both sides of the river. The length of the right wing is 2520 m while the left wing is 780 m. The dam is built in the shape of a pyramid where its width at the bottom of the river bed is 980 m and 40 m at the crest. The height of the dam above the river bed is 111m.

The body of the dam is constructed of granite blocks, sand and clay, in the midst of which is a clay core to prevent the seepage of water connected in the front part with a horizontal blanket of clay for the same purpose. Since the Nile bed, on which the dam is built, consists of sedimentary deposits, it was provided with a vertical injected curtain extending 170 m under the main core until it reached the solid layer stratum for foundation. The injected curtain is 40 m under the main core, and decreases until it reaches 5m at the point where it meets with the solid layer. (Eng. M. Kamal)

➤ **MEROWE**

The Merowe dam site is located downstream of the 4th cataract of the Nile River, about 350 km north of Khartoum. The dam is about 9.2 km long in total and consists of 311 m long homogeneous earth dyke and 4.4 km long major concrete face rock fill dam on the right bank 154 m long spillway and a 370 m long power intake dam in the right river channel and on the Marwa Island; and 841 m long major earth core rock fill dam in the left river channel and 1.4 km concrete face rock fill dam and 1.7 km long earth dyke on the left bank.



Figure 2-1 Map of Nile river basin and the locations of the targeted reservoirs
(World Bank , 2013)

2.2. Eastern Nile Hydrology

The Nile River is 6700 km long. It traverses international boundaries and travels through 11 riparian countries, from that the basic eastern Nile riparian countries are as shown in table 2.1 with variable water resources availability and dependency on Nile water. It has a total Catchment Area of 3 million km² its average runoff is 30 mm. The major part of the total flow comes from the Ethiopian Highlands and East African lake region. The Nile has three main tributaries, including the White Nile, Blue Nile and the River Atbara. This river crosses an extremely wide band of latitude originating at about 4°S and emptying at 32°N [Diana Rizzolio Karyabwite, 2000]

Table 2-1 Nile basin riparian countries (Emmanuel Olet, 2005; Nile Case Study)

Country	Area within the Nile basin(Km²)	% of the total Nile basin area	Country % in the Nile basin
Egypt	326,751	10.5	32.6
Eritrea	24,921	0.8	20.5
Ethiopia	365,117	11.7	32.4
Sudan (including south Sudan)	1,978,506	63.6	79.0

2.2.1. Flow Patterns

The Nile River's hydrology is highly influenced by the monsoon season. During the months of July-November the river Atbara and the Blue Nile contribute to the Nile's mean annual flow. Contrarily, the White Nile is not perennial, and as such, it produces a steady base flow year around [Emmanuel Olet, 2005].

The river is distinguished from other great rivers of the world by the fact that half of its course flows through the countries without the effective rainfall. Almost all the water of the Nile is generated on an area covering only 20 percent of the basin, while the remainder is in arid or semi-arid regions where the water supply is minimal and evaporation and seepage losses are very large.

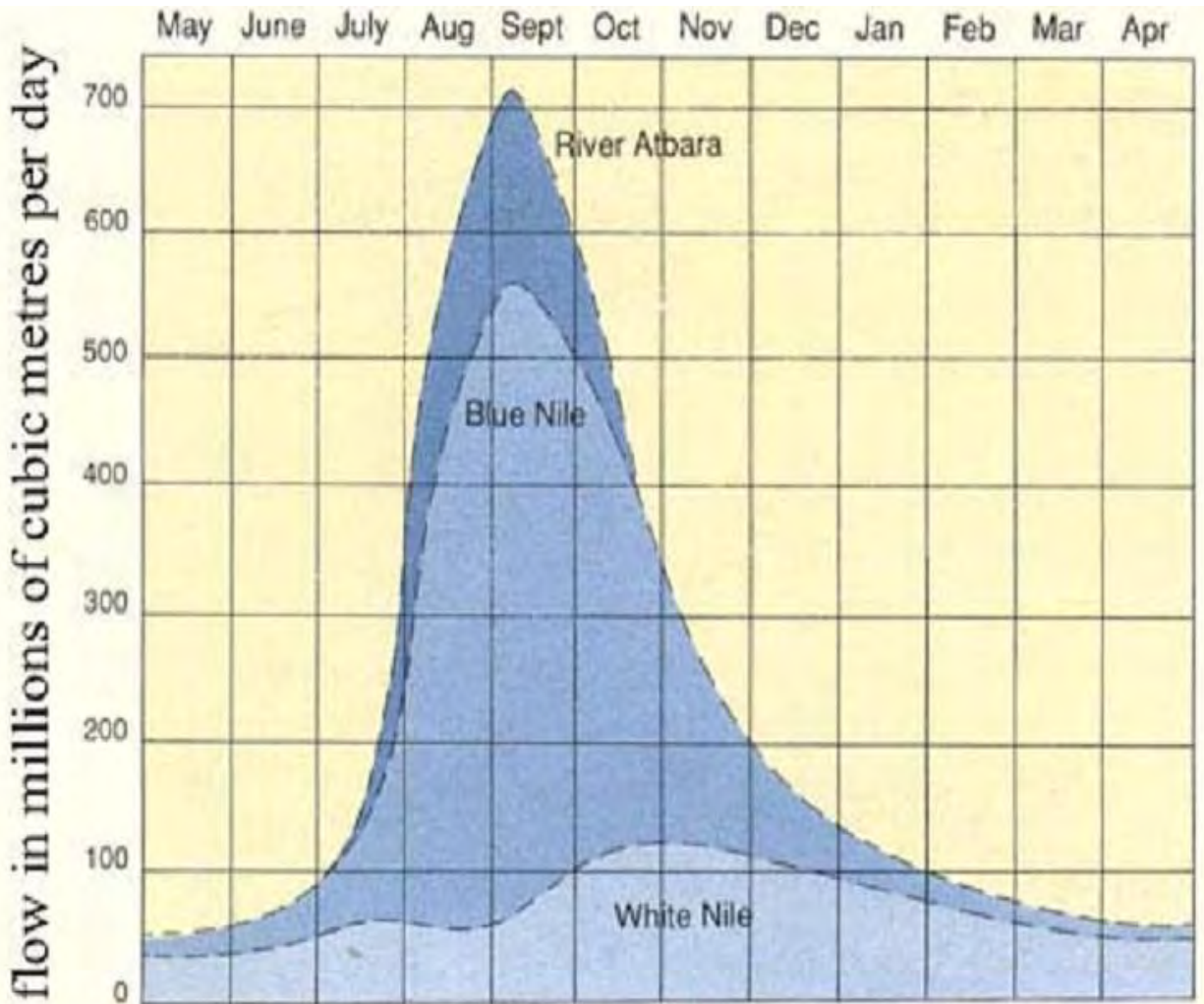


Figure 2-2 Annual flow pattern of Nile (Emmanuel Olet,2005)

Figure 2.2 indicates the cumulative contribution of the three riparian in million cubic meters per day. From the figure indicates Ethiopian blue Nile river contributes the greatest flow of the Nile around august to November.

CHAPTER THREE

3. LITERATURE REVIEW

To evaluate the potential impact of GERD on the downstream water uses of eastern Nile basin countries, it's important to review the literature which is done before and described the models, and methods of evaluations. The document reviewed in this paper is pervious study of eastern Nile basin by different authors, modeling of multi reservoirs in eastern Nile by different researchers.

Due to the complexity of river basin systems, it is not very easy to satisfy a large number of possible design and operating policies. Very often there is no assurance that the best combination of policies and structural measures can be found, especially when the river basin is large with a large number of reservoirs (or reservoir systems) and a large variety of short- and long-term interests that have to be satisfied. This requires computer based Decision Support Systems (DDS) that may provide balanced use of water as well as allow the decision maker to easily modify operating policy and physical and economic characteristics of a particular river basin. DSS is being used worldwide to manage more wisely our water resources. Labadie (2010) presents the role of DSS in achieving a sustainable use of water resources: "A Decision Support System allows decision-makers to combine personal judgment with computer output, in a user machine interface, to produce meaningful information for support in a decision-making process". Such systems are capable of assisting in solution of all problems using all information available on request.

3.1. Previous Studies in Nile Basin

The water balance of a river basin should ideally take into consideration the regulation effect of the existing, ongoing and constructed reservoir projects in the basin. Studies on such water balance so far have usually lacked consideration of aerial distributions in water availability and demand (utilization). These considerations could enable different reservoir projects situated in the concerned basins/sub - basins to be evaluated in an integrated manner. Without proper planning and management usage of single droplets of water within a given river basin without considering the riparian country may lead the socio-economic conflicts between the riparian countries.

In this context the vast Nile basin represents one of the critical, and perhaps the most important, shared water basin in Africa. A delicate conflict over the equitable allocation of the Nile waters represents one of the most critical issues in the African continent. Most of the riparian does not used for their development this is because of the countries remain politically unstable and suffer from famine and chronic mal-nutrition, limiting their ability toward social and economic development, stated as Fidel, Sayegh, and Khorbotly (2003).

However, upstream countries have begun to consider the Nile waters, in an attempt to initiate economic development and sustain their growing populations. Yet, the economic development sought by most countries of the Nile basin has been hindered (Varis, 2000; NBI, 2002).

For long period of time Egypt utilized the average annual flow at about 84 BCM, measured at Aswan high dam in Egypt, and estimated annual water loss due to evaporation and other factors at 10 BCM. The losses were deducted from the Nile yield of 84 BCM and the remaining water was divided among Egypt and Sudan as 55.5 and 18.5 BCM, respectively (Fidel, Sayegh, and Khorbotly, 2003).

3.2. Reservoir/River System modeling

3.2.1. General

Systems analysis as “in a generic sense, systems analysis can refer to any orderly and scientific approach to problem solving. It includes traditional engineering methods and more recently developed mathematical methods in the field of operations research”. A very large number of publications on applying systems analysis techniques to reservoir operation problems have appeared in the literature. They are all searching for a proper system analysis to obtain the best or optimum solution. Water resource system operation is usually analyzed using mathematical models, rather than with physical models.

3.2.2. River basin-Reservoir Simulation Model

Simulation is a modeling technique that is used to predict the behavior of the system under a given set of conditions, representing all the characteristics of the system largely by a mathematical or algebraic description (cited in Yeh, 1985). Simulation models are descriptive, and demonstrate what will happen if specified decisions are made. The assessment of system

performance can best be addressed with simulation models, whereas, optimization models tend to be more useful when system improvement is the main goal. Numerous Researchers have developed computer models for the operation of reservoirs and river systems. Now-a-days the majority of reservoir planning and operations are undertaken using simulation models.

However, the most effective strategy for analyzing river/reservoir operation problems may involve various combinations of optimization and simulation models. Simulation models are used to evaluate the consequences of a set of decisions (what-if analysis) over a hydrologic period of interest. The operation rule in a complex system involving many projects and purposes of development in a river basin system may be tested with the aid of simulation models. In a pure simulation model, reservoir releases are determined by a set of predetermined operating rules. Through a series of simulations these rules can be modified and improved until model results are judged acceptable. A reservoir system simulation model is based on a mass-balance accounting procedure for tracking the movement of water through a reservoir-stream system, and done by repeatedly solving the storage equation for a reservoir (inflow minus outflow equals change in storage) over a certain period. In a general form, the mass balance or quantity equation for reservoirs can be formulated as:

$$S_t = S_{t-1} + I_t - R_t - L$$

Where:

S_t is the reservoir storage at the end of time step t

S_{t-1} is the reservoir storage at the beginning of time step t

I_t is the inflow into the reservoir at time step t

R_t is the release for demands at time step t

L_t is the loss or water wasted from the reservoir at time step t.

Assessing the water availability more realistically, the regulation effect of storages of the existing, ongoing and contemplated reservoir projects is very significant and useful. As the literature review of a given point of interest the previous researchers work tells us about the planning and simulation of eastern Nile river basin reservoirs.

Different types of river-reservoir simulation operation modeling techniques have been applied to operate the basin as an integrated one. Some of the common and the most applicable reservoir operation models are:

HEC-5: - The program simulates the sequential period-by-period operation of a multiple-purpose reservoir system for inputted sequences of unregulated stream flows and reservoir evaporation rates. Multiple reservoirs can be located in essentially any stream tributary configuration. The program uses a variable time interval. For example, monthly or weekly data might be used during periods of normal or low flows in combination with daily or hourly data during flood events. The user specifies the operating rules in HEC-5 by inputting reservoir storage zones, diversion and minimum in stream flow targets, and allowable flood flows (Hydrologic-Engineering Center, 2007) .

WEAP:- Water evaluation and Planning Model. It is a simulation model develops to evaluate planning of management issue associated with water resource development. WEAP can be applied to both Municipal and agricultural systems and can address a wide range of issues including: Sector demand analysis, Water conservation, Water right and allocation priorities, stream flow simulations Reservoir operation and project cost benefit analysis.

MIKE BASIN: - runs within and is an extension to ArcView which is a geographical information system (GIS) software product available from ESRI (Environmental System Research Institute). MIKE BASIN integrates GIS capabilities with reservoir/river system modeling. Features also facilitate interconnected use of Microsoft Excel with MIKE BASIN. The model simulates multipurpose, multi-reservoir systems based on a network formulation of nodes and branches. Although the time step is user-selected, solutions are stationary for each time station without flow routing dynamics. Thus, a monthly time step is common. Time series of inflows from catchments to each branch of the stream system are normally provided as input. However, the model can also be connected to watershed precipitation-runoff capabilities provided by the MIKE11.

River Ware: provides the basic hydrologic capabilities associated with routing stream flow inflows through a river/reservoir system. Watershed runoff at pertinent river system nodes is provided as input. The primary processes modeled are volume balances at reservoirs, hydrologic

routing in river reaches, evaporation and other losses, diversions, and return flows. Features are also provided for modeling groundwater interactions, water quality, and electric power economics. Any number of reservoirs and stream reaches can be modeled. (Wurbs 2005).

Water Rights Analysis Package (WRAP): WRAP simulates management of the water resources of a river basin or multiple-basin region under a priority-based water allocation system. Basin wide interactions among numerous water uses and diverse water management facilities and practices may be modeled. The original model implemented in the Texas water management System is designed for long-term monthly time step modeling assessments of hydrologic and institutional water availability and reliability for water supply diversions, environmental in stream flow requirements, hydroelectric energy generation, and reservoir storage (Wurbs 2005).

MODSIM is a general-purpose reservoir/river system simulation model based on network flow programming designed for analyzing physical, hydrologic, and institutional/administrative aspects of river basin management. 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). Water is allocated based on user-specified priorities. The user assigns relative priorities for meeting diversion, in stream flow, hydroelectric power, and storage targets, as well as lower and upper bounds on flows and storages. The model computes values for all flows and storages. (Labadie et al. 1994; Dai and Labadie 2001)

3.3. Cascade Reservoir Operation in Eastern Nile River Basin

Reservoir operation is the technique used to allocate water stored in the reservoir among different upstream and downstream users. Reservoir operation is an important element in water resources planning and management. It consists of several control variables that defines the operation strategies for guiding a sequence of releases to meet many of demands from stakeholders with different objectives, such as flood control, hydropower generation and allocation of water to different users. A major difficulty in the operation of reservoirs is the often conflicting and unequal objectives. Therefore, it is necessary to optimize reservoir operation in determining balanced solutions between the conflicting objectives.

3.4. Modeling of Multi-Reservoirs in Eastern Nile

Many applications of science and public policy make use of models. A model is defined as an analytical tool which represents a simplified aspect of the real world (Stokey and Zeckhauser, 1978). Models contain a reduced amount of information that can be readily analyzed. By eliminating nonessential features of a study, models reduce the complexity of the problem at hand and emphasize what are thought to be the most important aspects. One major goal of model building is improved decision making. Therefore, the justification for using models as analytical tools must ultimately depend on their usefulness in aiding decisions. In addition to their use in decision making, the actual process of constructing a model often reveals relationships which were neither apparent nor understood at the beginning of the study. Another advantage of model building is that experimentation is possible with the model.

In the multi-reservoir applications different modeling approaches using systems analysis techniques were employed. These studies basically carried out planning and development of multi-reservoir systems. In another set of major developments in the modeling approach later, contributions from applications on several trans-boundary multi-reservoir river systems were made for the basins' integrated water resources developments in an optimal manner.

CHAPTER FOUR

4. METHODOLOGY

4.1. General

To achieve the objective of the research, evaluation of potential impacts of GERD on the downstream water use sectors of eastern Nile river basin, it is important to understand the hydrology, water use and configuration of the basin. The following are useful guides to choose appropriate water resource model configuration.

- ✓ Spatial configuration of the river basin system
- ✓ River basin hydrology
- ✓ Physical characteristics of reservoirs, hydroelectric power plants, and other water control facilities
- ✓ System operating rules
- ✓ Water use requirements

In this study was selected MODSIM model to computes reservoir storage, evaporation, hydroelectric power generation, and river flows for specified system operating rules and input sequences of stream inflows with evaporation rates. Hence, different data were collected from review of previous studies and data from institutions such as Nile Basin Initiatives (NBI), Ethiopian Electric Power Corporation (EEPCO) , the previously GERD 5250 MW hydroelectric power dam design reports.

After collecting the necessary data for this research MODSIM model is set up to simulate the recent condition within the catchment which will provide a “baseline” against which the existing and future scenarios can be compared.

4.2. Data Collection and Analysis

4.2.1. Inflow data

Monthly stream flow data of eastern Nile river basin from Jan 1956 to Dec2003 for 47 years of at three specified gaging station were collected from different sources: GERD design report and eastern Nile river basin master plan.

The first flow measuring station is Blue Nile immediately upstream its junction with the White Nile. The flow at this station contains seasonal flow Dinder and Rahad which originated in the highlands of Ethiopia in addition to flow from Sennar. The second one is Malakal discharge measuring station on the White Nile basin indicating the contribution of White Nile, Sobat River, and Bahr al-Ghazel basin. The last flow gauging station located at the outlet of the Atbara River immediately upstream of its Junction with the Main Nile. It joins the main Nile about 320 km downstream from Khartoum. There is a constructed dam on the river to serve for irrigation.

Table 4-1 Mean monthly stream flow data

Month	Blue Nile flow (MCM)	Malakal flow (MCM)	Atbara flow (MCM)
Jan	878.87	2863.4	57.2
Feb	532.25	1882.6	36.0
Mar	453.50	1950.0	34.4
Apr	469.83	1690.6	38.3
May	663.25	1867.0	52.0
Jun	1891.43	2121.5	330.7
Jul	8334.16	2720.2	2307.0
Aug	14589.90	3070.2	6278.9
Sep	12560.36	3127.8	2752.7
Oct	7161.23	3517.1	765.2
Nov	2929.93	3342.2	215.0
Dec	1419.40	3332.7	104.5

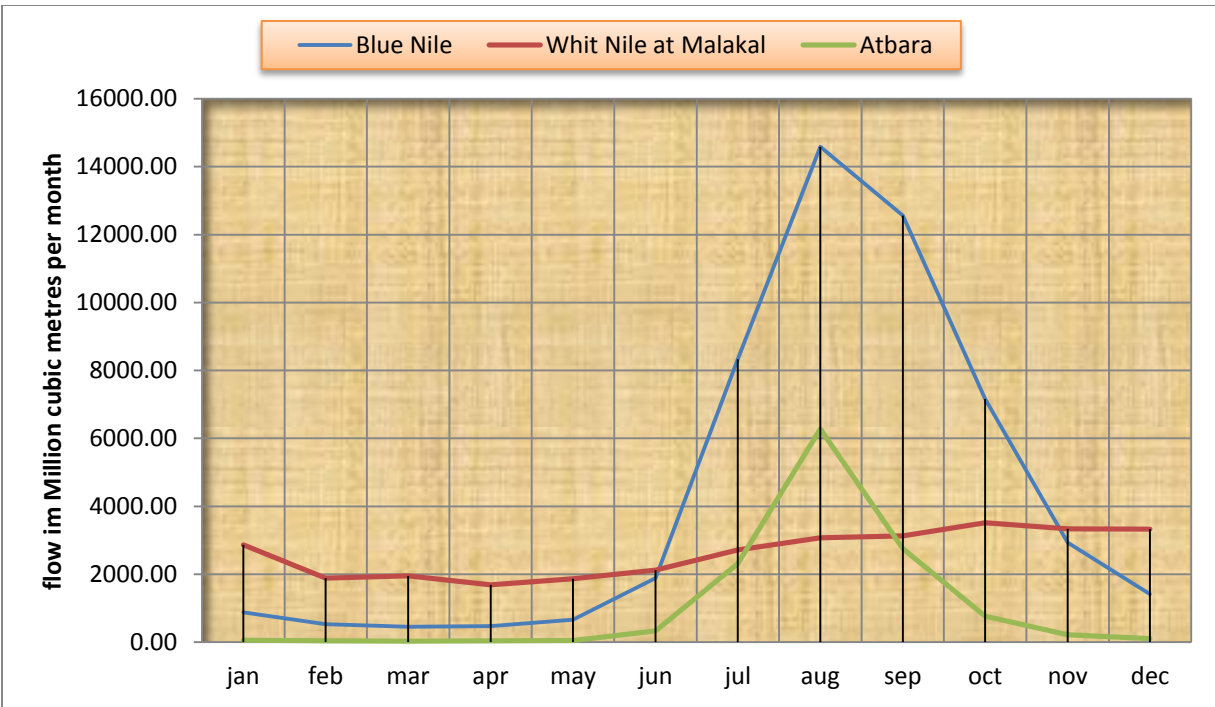


Figure 4-1 Mean monthly flow of eastern Nile

4.2.2. Reservoir data

4.2.2.1. Physical characteristics data

MODSIM accommodates multiple multi-purpose reservoir systems. Individual reservoirs can simulate the performance of specified operating policies using associated operating rule curves. These define the desired storage volumes, water levels and releases at any time as a function of existing water level, the time of the year, demand for water and possibly expected inflows.

The reservoir dialog is used to describe the reservoir characteristics, operating rules, and upstream- and downstream connections to users and control nodes are specified

In summary

- HAD reservoir characteristics required for Water Level (NWL) is equal to 183 m.a.s.l. The Minimum Operating Level (MOL) is equal to 147 m.a.s.l.
- Merowe reservoir characteristics as a minimum operating level of 285 m.a.s.l. and full capacity level (FSL) are at 300 m.a.s.l.
- GERD reservoir characteristics as a minimum operating level of 590 masl and full capacity level (FSL) is at 640 masl

4.2.2.2. Evaporation Loss data

The loss of water by evaporation must be considered from an open water surface EO, is the direct transfer of water from lakes, reservoirs and rivers to the atmosphere. Mean monthly evaporation data for each existing and proposed reservoirs were obtained from their respective study documents.

Table 4-2 Monthly net evaporation losses (m/month)

RESERVOIR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GERD	0.135	0.136	0.171	0.157	0.106	0.042	0.000	0.001	0.014	0.091	0.114	0.115
MEROWE	0.197	0.222	0.295	0.331	0.365	0.34	0.314	0.303	0.317	0.307	0.231	0.199
HAD	0.123	0.128	0.168	0.196	0.243	0.262	0.26	0.254	0.237	0.214	0.166	0.133

4.2.3. Hydropower data

Hydropower generation is simulated by inserting a hydropower node and connects it to a reservoir using the channel feature.

The time series data contains the following items:

- discharge [m^3/s or equivalent]
- hydropower Installed capacity
- Minimum head for operation of turbines. If head (difference between reservoir level and tail water level) drops below this threshold, no water is routed through the turbines, regardless of power demand

All input data which enable running simulation are obtained from Ethiopian Electric Power Corporation (EPCO) Grand Ethiopian Renaissance Dam Project reports.

Installed power at HAD and MEROWE is equal to 2,100 MW and 1200 MW respectively and for GERD 6000 MW power with turbines efficiency equal to 95 % (GERD Design reports).

4.2.4. Irrigation water use data

The most common water use in Nile river basin is irrigation and hydropower use. The temporal variation in the extraction of water is described by a time series file for each water user node. The temporal variation of return flow of water that is assumed not to be consumed at the water user node can be transferred back to one or more river nodes.

The water system retained for the purpose of this study will assume water use for irrigation purposes in Sudan and Egypt shown in table 4.3. HAD outflows aim to satisfy Egyptian irrigation water uses(Tractebel Engineering, EEPSCO). To summarize the tables 55.5 BCM/year are Egyptian uses downstream of HAD and 18.5 BCM/year is Sudan irrigation use. Thus, the value of 18.5 BCM/year corresponds to the remaining water volume of the natural Nile flow arriving at HAD (84 BCM/year in average).

Table 4-3 Monthly water volume allocated to irrigation in Egypt and in Sudan (BCM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
Irrigation in Egypt	2.55	3.36	4.22	4.31	5.54	7.26	7.35	6.33	4.5	3.6	3.33	3.16	55.5
Irrigation on blue Nile	0.43	0.56	0.71	0.72	0.93	1.22	1.23	1.06	0.76	0.6	0.56	0.53	9.33
On the intermediate catchment	0.42	0.55	0.7	0.71	0.92	1.2	1.21	1.05	0.74	0.59	0.55	0.52	9.17

This 18.5 BCM/year of water are tapped at two different points upstream of HAD in the water system model 9.33 BCM/year are deducted on the Blue Nile River to irrigate lands around Sennar; 9.17 BCM/year are deducted on the intermediary catchment (on the White Nile River and on the Atbara River) Water volumes for irrigation in Sudan are deducted from the Nile upstream of HAD, and thus are prevented to enter in HAD reservoir in the proposed model.

4.3. Tools

The tools used for this research are MODSIM model for basin simulation and Microsoft EXCEL 2007 to analyze MODSIM outputs.

4.3.1. MODSIM (River Basin Simulation and Planning Model)

MODSIM is a generic river basin planning management decision support system models originally conceived in 1978 at Colorado State University (Labadie, 2010), making it the longest continuously maintained river basin management software package currently available. The most recent version MODSIM 8.1 is developed under the Microsoft .NET Framework and is comprised entirely of native code written in MS Visual C++ (Labadie, 2005).

MODSIM is designed as a generalized river basin management decision support system (DSS) designed as a computer-aided tool for developing improved basin wide and regional strategies for short-term water management, long-term operational planning, drought contingency planning, water rights analysis and resolving conflicts between urban, agricultural, and environmental concerns(Labadie,2010). Defined a DSS as “an interactive computer-based support system that helps decision makers utilizes data and models to solve unstructured problems”.

MODSIM provides both a planning framework for integrated river basin development and management, as well as aid in real-time river basin operations and control.

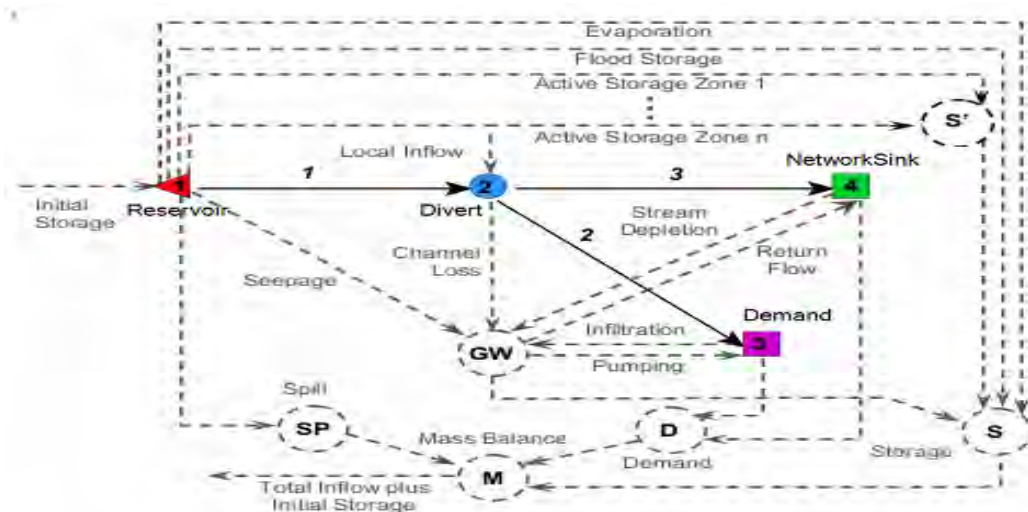


Figure 4-2 MODSIM network structures with artificial nodes and links

4.3.2. MODSIM GUI Graphical User Interface

The graphical user interface (GUI) for MODSIM as shown in Figure 4.3 provides spatially-referenced database capabilities allowing users to create and link river basin network objects on the display, and then populate data for that object by right-mouse click to activate the object and open its tabbed database form. GIS raster layers may be imported into the GUI as background maps for network creation. Lengthy time series data for unregulated stream flows, demands, etc., can be loaded by copying data from EXCELTM (Microsoft, Inc.) to the MS Windows clipboard and pasting the data into the appropriate Node Properties form, or importing directly from database management systems. The main Menu Bar for MODSIM includes items to load and save a MODSIM network, import and export data, select English or metric units, search for specific nodes and links, provide zoom control, execute the model, select and display graphs; create, edit and generate tabular reports; access various utilities, print out the network, and more.

A powerful GUI connects MODSIM with database management components and an efficient network flow optimization model. The objective function and all constraints on the network flow optimization are automatically constructed in the GUI, thereby relieving the user from having to acquire proficiency in optimization modeling or computer programming. Optimization of the objective function essentially provides an efficient means of assuring that all system targets and guide curves are achieved according to user-specified priorities based on water rights or economic valuation, while insuring that water is allocated according to physical, hydrological, and institutional/legal/administrative aspects of river basin management.

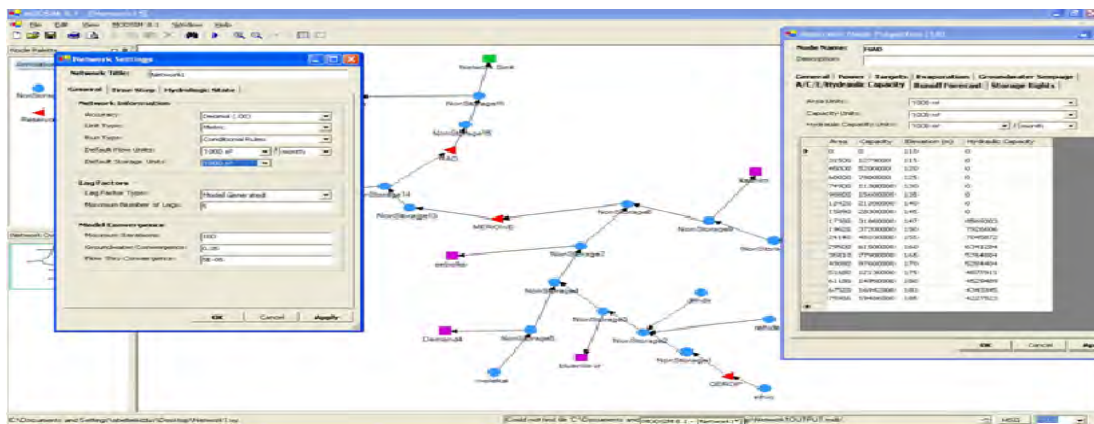


Figure 4-3 MODSIM river basin simulation model for project area

4.3.3. MODSIM Interface

The interface contains icons in the Node Palette Window for creating storage, demand, and non storage (points of confluence or diversion) nodes in the network by simply dragging them into the Network Editor Window, or left-button mouse clicking on the icon and then clicking on the Link or arc objects are created directly in the Network Editor Window by moving the cursor onto the origin node, holding down the left-mouse button, and then dragging the pointer to the desired ending node, which also sets the flow direction for that link. Links can be segmented by user specification of any number of vertices, allowing any desired link shape. Multiple links connecting the same two nodes are easily created by selecting Convert to Multilink in the context menu for any link. Tools are available for deleting or moving nodes or groups of nodes, as well as copying node attributes to any user-selected node. The Network Overview Window is useful for large networks where the display window can be panned over any portion of the network.

4.3.4. Why MODISM

- ✓ MODSIM has been applied to a wide range of basins including municipal raw water distribution systems, river basins dominated by irrigated agriculture, and large-scale interstate basins
- ✓ There is no basin-scale limitation in MODSIM
- ✓ MODSIM essentially utilizes a network flow optimization algorithm to accurately simulate a priority-based water allocation system, while still providing mechanisms for equitable sharing of limited water resources. The computational speed and efficiency of the optimization algorithm provides for long-term risk evaluation and development flow-duration curves using Monte Carlo methods.
- ✓ MODSIM is based on the hypothesis that any complex river basin system can be represented in a network formulation composed of interconnected nodes and links. Storage nodes include reservoirs (both on-stream and off-stream), storage accounts, and groundwater aquifers. Non storage nodes include demand locations, points of inflow, diversion, confluence, or any intermediate point to better represent heterogeneity of basin characteristics. Any non point basin characteristic such as channel losses and local storm runoff along a river reach are assumed to be aggregated at one or more nodes. Network links or arcs represent river reaches, canals, pipelines, and drains. The network flow

structure is based on linear algebraic equations that conserve mass balance, while maintaining capacity bounds on flows throughout the system.

The figure 4-4 shows that the nodes and links of the MODSIM models and its data entry requirements.





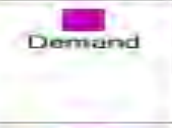

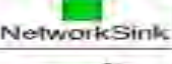
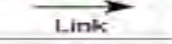
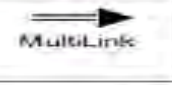

Icon	Functionality	Data Requirements
 Reservoir [Operations]	<ul style="list-style-type: none"> Main-stem and offstream reservoir operations Flood control, conservation pools; dead storage Zones for storage balancing in multi-reservoir systems 	<ul style="list-style-type: none"> Elevation-area-capacity tables Maximum, minimum, initial storage Reservoir storage guidecurves Reservoir balance tables Hydraulic outlet capacity tables Net evaporation loss; seepage Inflow forecasts (if available)
 Reservoir [Hydropower]	<ul style="list-style-type: none"> High-head hydropower Run-of-river hydropower (0 storage) On-peak, secondary and firm energy Pumped storage 	<ul style="list-style-type: none"> Nonlinear efficiency tables as functions of head and discharge Tailwater-discharge tables Powerplant capacity Load factors for pumped storage
 Storage Right Reservoir	<ul style="list-style-type: none"> Storage right accounts Storage ownership maintenance Water banking and service contracts 	<ul style="list-style-type: none"> Storage right users Group ownerships
 NonStorage	<ul style="list-style-type: none"> Watershed runoff Tributary inflow Flow confluence and diversion Groundwater return flows Stream depletion from pumping 	<ul style="list-style-type: none"> Imported inflow time series data Execution of external rainfall-runoff models through custom code
 Demand	<ul style="list-style-type: none"> Consumptive demand Groundwater pumping Stream-aquifer modeling with Glover model or USGS stream depletion factor (sdf) method 	<ul style="list-style-type: none"> Import of demand time series data External consumptive use models Demands/priorities conditioned on hydrologic state Water use efficiency (time variable) Aquifer parameters; pumping capacity
 Flowthru	<ul style="list-style-type: none"> Instream flow requirements: environmental, ecological or navigation purposes Nonconsumptive demands Gaging station for model calibration 	<ul style="list-style-type: none"> Time series of instream flow requirements Flow-through demands and priorities vary with hydrologic conditions Measured flow data for calibration
 NetworkSink	<ul style="list-style-type: none"> River basin outlet (multiple outlets for several basins allowed) 	
 Link	<ul style="list-style-type: none"> Channel losses Maximum and Minimum Flow 	<ul style="list-style-type: none"> Time series of maximum capacities Link costs and benefits
 MultiLink	<ul style="list-style-type: none"> Represent nonlinear discharge-channel loss functions Nonlinear cost-discharge functions Multiple water sources and rights 	<ul style="list-style-type: none"> Time series of maximum capacities Link costs and benefits
 Routing Link	<ul style="list-style-type: none"> Streamflow and channel routing 	<ul style="list-style-type: none"> Muskingum method coefficients User defined lag coefficients

Figure 4-4 MODSIM functionality and features

4.4. Input Data Requirements of the model

MODSIM provides an intuitive object-oriented graphical user interface for input of all data.

▪ **Storage node data include:**

- Reservoir name, minimum volume, maximum volume, and initial contents
- Hydropower efficiency tables related to flow and head on turbines, including consideration of tail water conditions

- Target storage tables and operating rules
- Reservoir storage priorities and conditional operating rules
- Surface area, capacity, head, and hydraulic outlet capacity tables
- Net evaporation rate tables
- On-peak hours of generation for hydropower plants
- Reservoir balance tables dividing reservoirs into several zones for balanced operations in a multi-reservoir system
 - **Non storage node data include:**
 - Node name and description
 - Unregulated inflows
 - In stream flow (flow-through) demands and associated priorities
 - Consumptive demands and associated priorities
 - **Link data include:**
 - Link name, minimum and maximum capacity
 - Time variable capacity information
 - Channel loss coefficients
 - Costs per unit flow
 - Water right priority dates
 - Seasonal capacity limitations
 - Designation of return nodes for channel losses
 - Hydrologic routing parameters
 - Administrative information on storage accounts and exchanges

4.5. Network Flow Optimization in MODSIM

A MODSIM network is comprised of interconnected nodes with unidirectional links. Nodes can be classified as non-storage nodes, demand nodes, reservoir nodes, or network sinks. Non-storage nodes are inflow locations where water can flow into the system. Demand nodes represent consumptive uses, where flow leaves the system. Reservoir nodes are storage nodes that simulate reservoir operations. Network sinks convey flow out of tile network. Links convey flow from node to node. MODSIM optimizes tile network flow-cost problem to distribute water

among competing users in the system. Cost is a way of preferentially driving flow to one place in the network over another. The more negative the cost, the more the model will drive water in that direction. The design of cost structures in the MODISM network allows simulation of the prior appropriation doctrine and other complex administrative rules. The model converts node priorities to costs, using

$$cost = -50,000 + (10 * priority)$$

The node costs are then combined with tile costs of the model links. The sum of all flows multiplied by the cost at each time step is minimized to solve tile network flow cost problem. Since MODSIM is capable of differentiating between direct flow and storage water, it has the capability to simulate the allocation of different categories of water. MODSIM simulates water allocation mechanisms in a river basin through sequential solution a network flow optimization problem for each time period $t = 1, \dots, T$:

$$\underset{k \in A}{\text{minimize}} \quad C_k q_k$$

Subject to:

$$q_k - \sum_{j \in I_i} q_j = bit_i \quad \text{for all nodes } i \in N$$

$$I_{kt}(q) \leq q_k \leq u_{kt}(q) \quad \text{for all links } k \in A$$

Where A is the set of all arcs or links in the network; N is tile set of all nodes; O_i is the set of all links originating at node i (i.e., outflow links); I_i is the set of all links terminating at node i (i.e., inflow links); bit_i is the (positive) gain or (negative) loss at node i at time t ; q_k is the flow rate in link k ; c_k are costs, weighting factors, or water right priorities per unit flow rate in link k ; and I_{kt} and u_{kt} are specified lower and upper bounds, respectively, on flow in link k at time t . Note that parameters bit_i , I_{kt} , u_{kt} are defined as functions of the flow vector q in the network.

4.6. MODSIM model output control

MODSIM provides both graphical plots and tabular output of time series information of: storage, flow, reservoir releases, inflows, demands, shortages, groundwater contributions. Users are provided many types of chart options for graphical output display, including 3-dimensional and multi-axis displays. In addition to time series results, probability and flow-duration curves

are also available. A powerful scenario analysis tool allows comparative evaluation of the results from several MODSIM runs under different management schemes. Output can also be displayed in any desired units, independent of the original time series data units. An animated output feature is now available in vs. 8.1 which displays movie of the simulation run, with changing sizes and colors of network objects depicting changing flow and storage conditions.



Figure 4-5 MODSIM model output controls

4.7. Model Efficiency

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods, these numerical model performance measures are coefficient of regression (r^2 coefficient) and the Nash-Suttcliffe simulation efficiency (ENS).

The range of values for r^2 is 1.0 (best) to 0.0 (poor). The r^2 coefficient measures the fraction of the variation in the measured data that is replicated in the simulated model results. A value of 0.0 for r^2 means that none of the variance in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.

Nash-Sutcliffe simulation efficiency, ENS, indicates the degree of fitness of the observed and simulated plots with the 1:1 line. It is calculated as follows with the same variables defined above:

$$E_{NS} = 1 - \frac{\sum_{i=1}^n (q_{oi} - q_{si})^2}{\sum_{i=1}^n (q_{oi} - q_o)^2}$$

Where;

q_{si} is the simulated values of the quantity in each model time step (in this case, monthly and yearly)

q_{oi} is the measured values of the quantity in each model time step (in this case, monthly and Yearly)

The statistical index of modeling efficiency (ENS) values range from 1.0(best) to negative infinity. ENS is a more stringent test of performance than r^2 and is never larger than r^2 . ENS measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison. A value of 0.0 for ENS means that the model predictions are just as accurate as using the measured data average to predict the measured data. ENS values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average. This measure is highly affected by a few extreme errors and can be biased if a wide range of events is experienced.

CHAPTER FIVE

5. RESULTS AND DISCUSSION

5.1. Model Calibration and Validation results

5.1.1. Model calibration

In the calibration we attempted to minimize model errors of the river flows. Thus model calibration involves modifications of model parameters values and comparison of predicted output to the measured data until a defined objective function is achieved.

Automatic calibration capabilities are not provided in MODSIM, although the flow through demand construct allows import of measured flows at stream flow gages and specification of measured reservoir volumes as target levels given a high priority. In this way, parameters can be adjusted and deviations between simulated and measured flows and storage levels analyzed. Although all calibration is conducted by' the user through trial-and-error adjustments, the graphical user interface incorporated within MODSIM greatly facilitates this process. Calibration of the models have been analyzed on two main points on the stream of Nile river basin at the confluence of white Nile and blue Nile at Tamaniat and the other points are beyond the Merowe dam, outlet of Nile at Sudan boarder; Dongola .

Table 5-1 Simulated and observed data at Dongola and Tamaniat station (calibration)

TIME	Model efficiency (Month)			
	Dongola		Tamaniat	
1956-1972	R^2	N_{SH}	R^2	N_{SH}
	0.93	0.7	0.92	0.9

The calibration period is from Jan 1956 to Dec 1972. The calibration results are given in Figure4.5 .The overall performance of the model during calibration has been measured using Nash-Sutcliffe (NS) and r^2 .

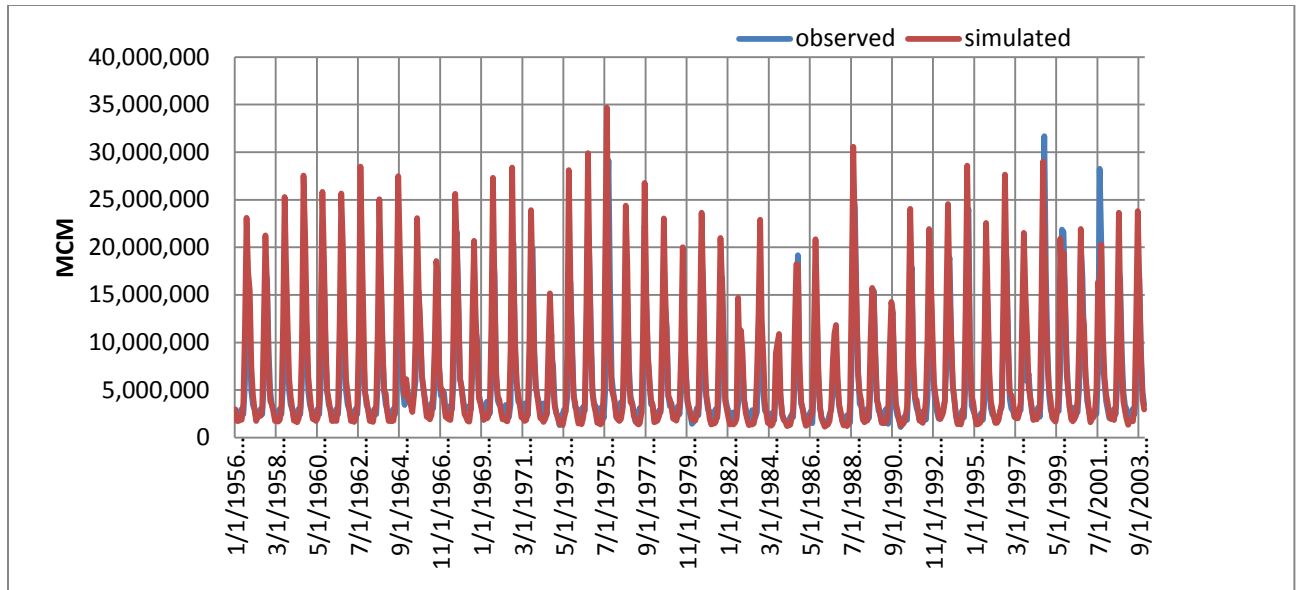


Figure 5-1 Model Simulated vs observed inflow time series monthly data at Dongola station

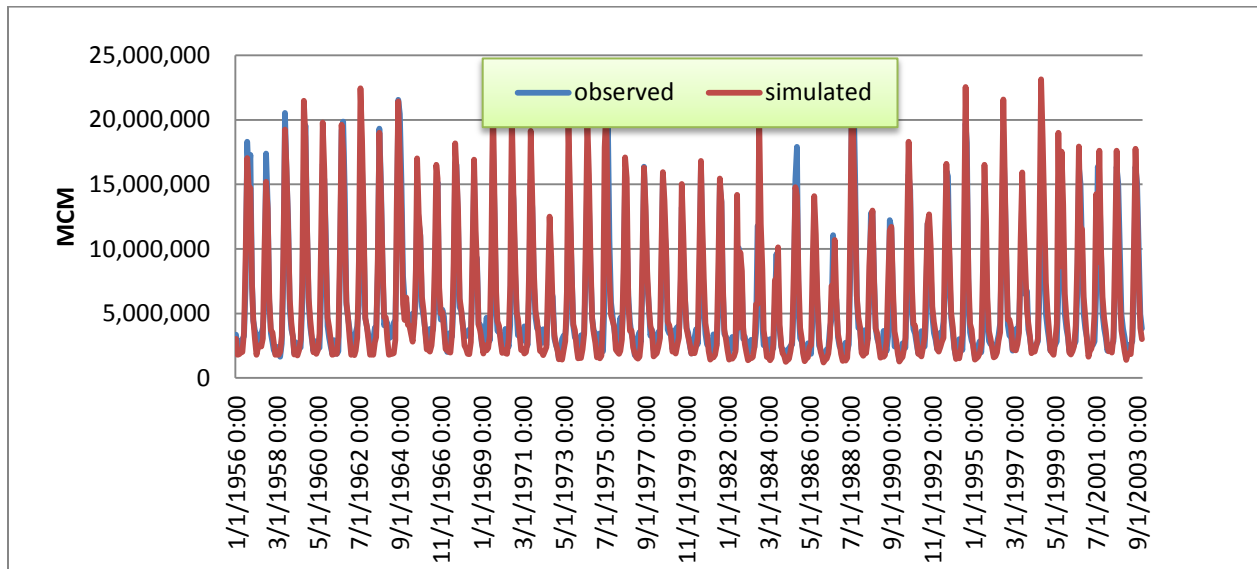


Figure 5-2 Calibrations of simulated vs observed inflow time series monthly data at Tamaniat

5.1.2. Model validation

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Thus, the model was validated with observed flow data at the same gauging station, but for the period from Jan 1973 to Dec 2003. Appendix 3.2 and Appendix 3.4 presents the

validation results. The model performance was assessed using the Nash-Sutcliffe (NS) coefficient, and r^2 .

Table 5-2 Simulated and observed at Dongola and Tamaniat station (validation)

TIME	Model efficiency (Month)			
1973-2003	Dongola		Tamaniat	
	R^2	N_{SH}	R^2	N_{SH}
	0.8	0.72	0.81	0.8

5.2. Simulation Scenarios

For evaluating the GERD on downstream water uses of eastern Nile river basin countries, four different scenarios have been considered. The first one is base line scenario which means without the newly constructed GERD. The second and third scenario is during construction/ impounding stages of GERD which is 6 years period. In this case two different scenarios are applied based on the sequence of observed HAD inflows during the following period of the normal flow and dry flow.

a) the normal impounding scenario to analyze GERD impounding stage and its downstream impacts, especially on HAD and Merowe operation, considers an average sequence of 6 years flow which is approximately equal to the long term average flow of main Nile at HAD (84 BCM) The period of 6 years which presents the closest mean value to the average HAD naturalized inflows value on the whole available period has been selected; which is 1973-1978.

b) the driest impounding scenario A critical case for GERD impounding stage and its downstream impacts, especially on HAD and Merowe operation , considers a sequence of dry years related to HAD inflows. To select this sequence, the 6- year average curve on HAD time-series from 1983-1988 is the driest 6 years period.

The fourth scenarios is the long term future scenario with its downstream impacts on both water use sectors based on the feature hydrologic data 2020-2067.

In all scenarios all irrigation demands downstream of GERD remains unchanged 55.5 BCM/year for Egyptian and 18.5 BCM/year for Sudan's.

5.2.1. 1st scenario: Base line scenario

This base line scenario considering the river basin as it is without the newly under constructed GERD dams. This scenario is a reference scenario used to evaluate the other scenarios after the implementation of GERD. This scenario considers the Nile flow as it is within the regulated period of Jan 1956 to Dec 2003.

➤ Results

- Merowe

The simulation result of Merowe without the newly under constructed GERD dam is put it hear as in mean monthly values of inflow ,outflow, evaporation loss, reservoir storage level and the generated energy amounts. The results are summarized in table 6 and table 18 in appendix parts.

Table 5-3 Average monthly simulation results of Merowe during base line scenario

Month	Inflow (MCM)	Outflow (MCM)	Evaporation loss (MCM)	Reservoir storage elevation(m)	Energy generated
Jan	2897.68	2855.49	69.90	285	338.55
Feb	1806.06	1727.47	78.59	285	205.85
Mar	1849.90	1745.47	104.43	285	208.00
Apr	1783.32	1666.15	117.17	285	198.57
May	2093.96	1964.75	129.21	285	234.08
June	3345.48	3225.12	120.36	285	380.99
July	11982.83	11871.68	111.16	285	922.48
Aug	22624.72	22517.46	107.26	285	657.20
Sep	16732.15	16619.93	112.22	285	900.00
Oct	9651.02	9542.34	108.68	285	855.90
Nov	5000.83	4919.06	81.77	285	545.44
Dec	3874.32	3803.88	70.45	285	446.78
Yearly	83642.28	82458.79	1211.2	285.00	5893.85

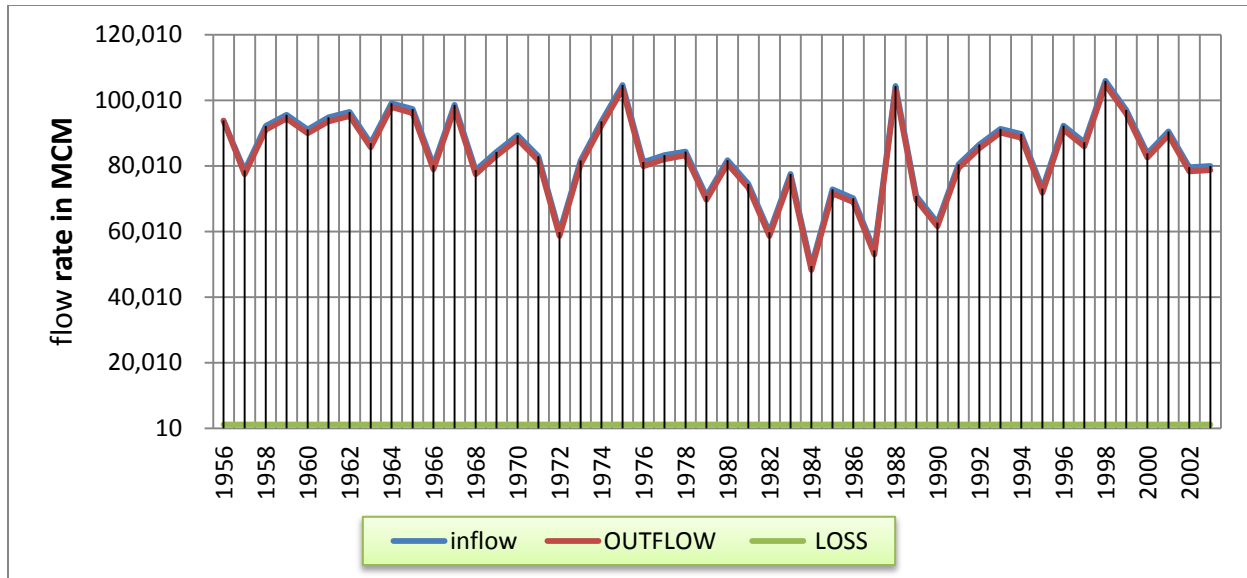


Figure 5-3 Average yearly inflow outflow and evaporation loss of Merowe during base line scenario

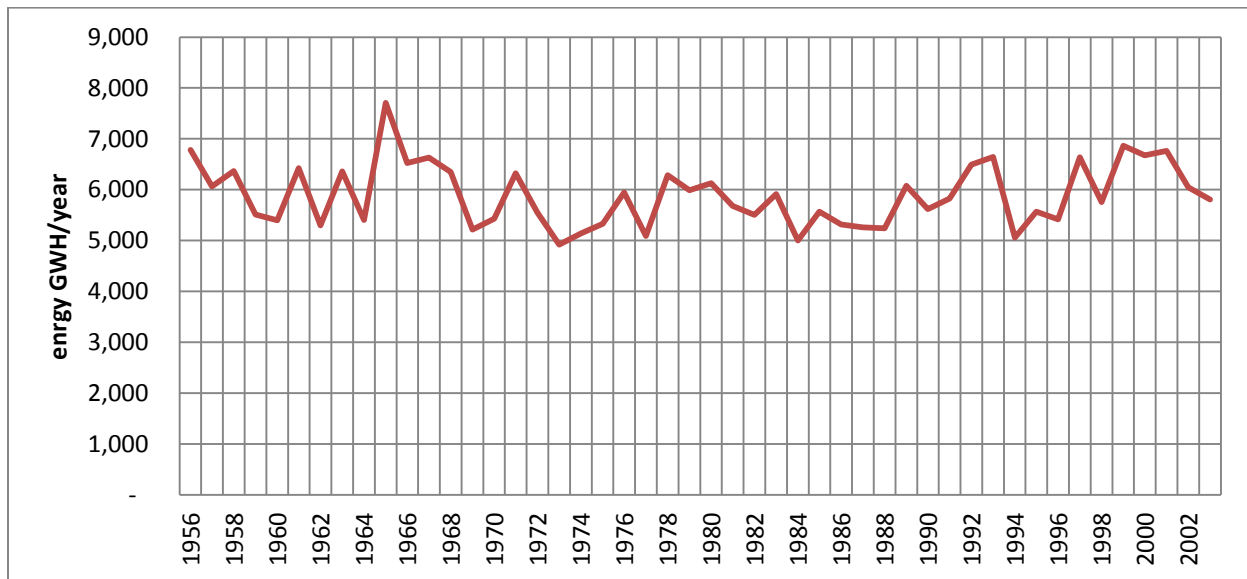


Figure 5-4 Average yearly energy production of Merowe during base line scenario

- **High Aswan Dam**

The simulation result of High Aswan Dam without the Nile flows abstracted due to the newly under constructed GERD dam is put it hear as in mean monthly values of inflow ,outflow,

evaporation loss, reservoir storage level and the generated energy amounts. The results are summarized in table 5.4 and table 19 in appendix parts

Table 5-4 Average monthly simulation results of High Aswan Dam during base line scenario

Month	Inflow (MCM)	Outflow (MCM)	Evaporation loss (MCM)	Reservoir storage elevation(m)	Energy generated
Jan	2819.49	2719.01	560.24	175.98	469.90
Feb	1701.46	3360.00	580.73	175.55	575.00
Mar	1690.91	4220.00	776.97	174.92	710.44
Apr	1601.14	4310.00	899.03	174.2	717.44
May	1895.32	5540.00	1101.53	173.18	898.46
June	3164.83	7260.00	1147.06	172.03	876.39
July	11821.19	7350.00	1127.60	172.72	878.58
Aug	22483.04	7754.04	1174.49	175.4	992.51
Sep	16606.09	11850.30	1159.90	176.08	413.98
Oct	9529.94	7817.18	1052.80	176.19	931.73
Nov	4900.47	4059.21	795.69	176.18	693.87
Dec	3764.21	3426.57	616.61	176.1	589.45
yearly	81978.11	69666.31	10992.65	174.88	8747.75

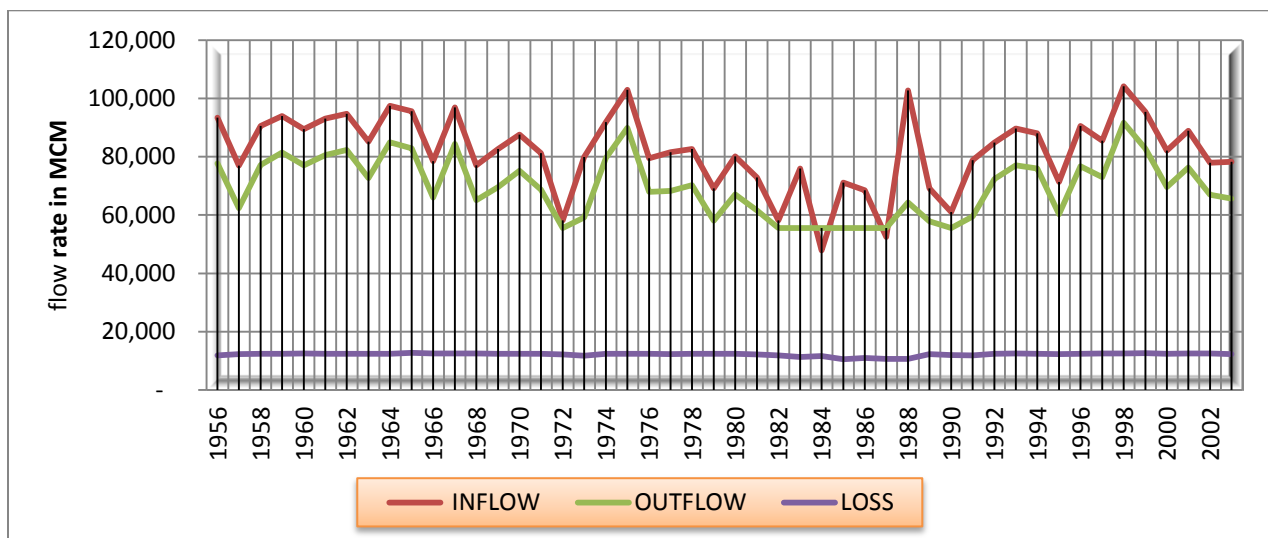


Figure 5-5 Average yearly inflow outflow and evaporation loss of HAD during base line scenario

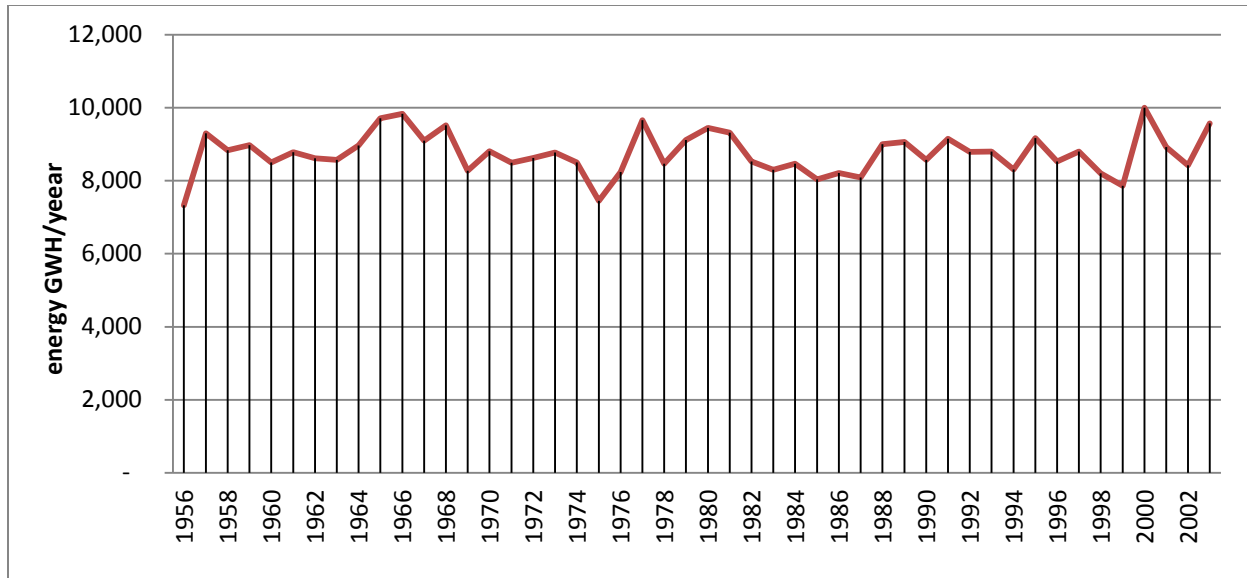


Figure 5-6 Average yearly energy production of HAD during base line scenario

5.2.2. 2nd Scenarios: Normal Flow impounding scenario

The normal flow impounding considers an average sequence of 6 years flow at GERD in the basis of normal flow at HAD. The period of 6 years which presents the closest mean value to the average HAD naturalized inflows value on the whole available period has been selected.

- 2014 – 2019 flows will be equal to 1973 – 1978 flows from the available inflow series. It corresponds to the sequence of average years.

➤ Results

▪ GERD

- GERD water level in the reservoir will reach the minimum operation level 560 masl in August 2014
- Considering an average sequence of years from a hydrological point of view, GERD will reach its normal water level (640 masl.) In the end of the simulation periods of 2019. Thus, 6 years may be required to fill GERD till its NWL;
- Yearly mean annual GERD inflow and outflows during the impounding stage will be equal to 49,853 MCM and 18,444MCM respectively.

- Energy generation will be limited during the impounding stage, the mean yearly values is 6,105 GWh/year.
- In this impounding stage 1.713 BCM of water is lost due to the reservoir evaporation losses.

Table 5-5 GERD normal flow impounding scenario simulation results

year	Inflow	Outflow	Loss	Elevation	Energy
	MCM	MCM	MCM	m	GWh/y
2014	46546.00	2614.10	543.02	577.85	555.02
2015	51418.00	8125.69	1666.87	628.72	2064.28
2016	55613.00	24323.38	2006.50	638.19	8262.69
2017	47241.00	25541.91	2032.28	638.67	8683.39
2018	49616.00	28379.65	2001.86	637.49	9595.87
2019	48686.00	21684.89	2026.26	639.15	7467.52
Mean	49,853.33	18,444.94	1,712.798	626.678	6,104.795

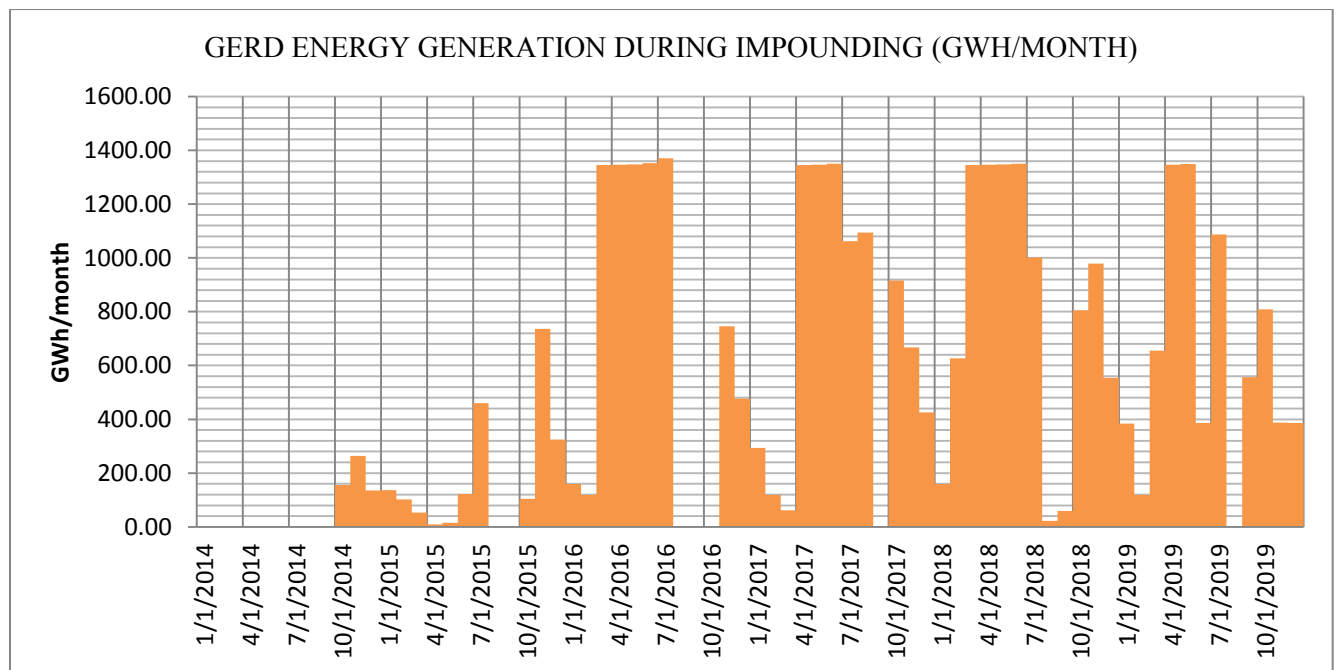


Figure 5-7 Monthly energy production of GERD during normal flow impounding scenario

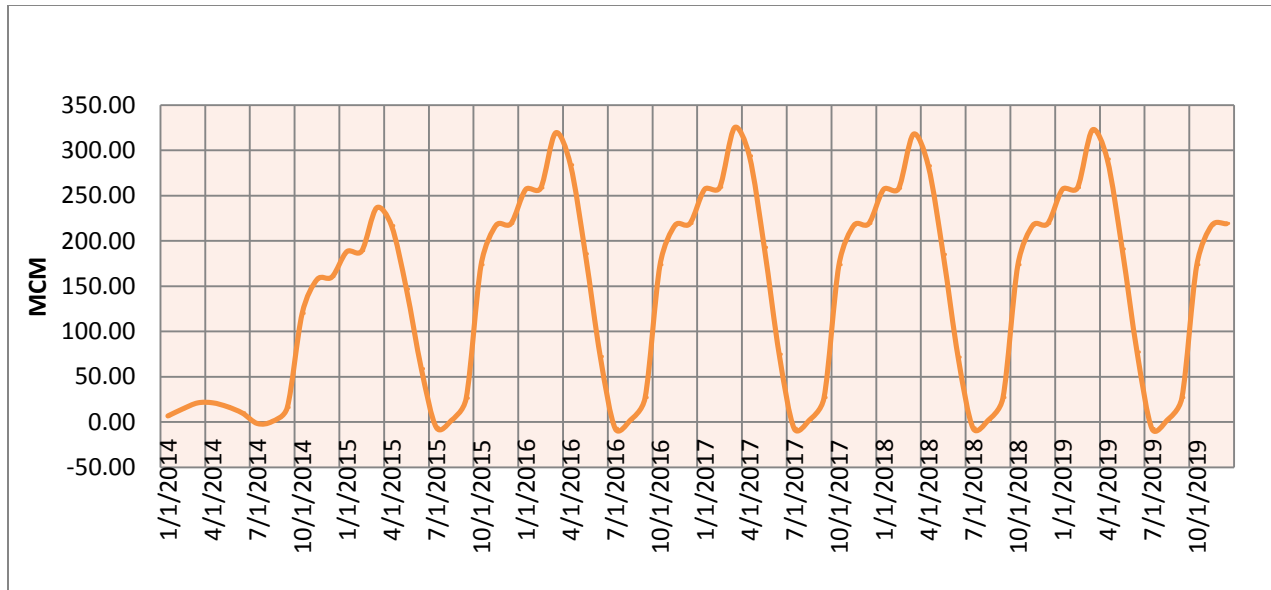


Figure 5-8 Monthly evaporation loss of GERD during normal flow impounding scenario

▪ **Merowe**

Table 5.6 and figure 5.9 to 5.11 summarize Merowe simulation results considering GERD upstream during its impounding periods. To summarize the results

- During average impounding the reservoir yearly mean water level is reached 291.71m and not lower than the minimum operating level 285m throughout simulation periods.
- The Merowe mean annual inflow- outflow during impounding periods equals to 57,582 MCM for inflow and mean yearly outflow is 52,696MCM is respectively inflow-outflow.
- The mean annual loss 1.82BCM and the yearly average energy production during these average impounding periods will be equal to 6,826 GWH/year. GERD will not affect MEROWE reservoir power and energy production rather than increasing the total production

Table 5-6 Merowe normal flow impounding scenario simulation results

year	Inflow	Outflow	Loss	Irrigation water use Shortage of Sudan	Elevation	Energy
	MCM	MCM	MCM	(%)	m	GWH/y
2014	40,898.45	40,030.93	1,546.19	-25	288.6006	5,050.59
2015	49,984.03	39,466.43	1,746.47	+2	291.0764	5,348.29
2016	73,198.00	59,052.01	1,879.47	+1	292.4848	7,580.47
2017	59,434.54	59,322.61	1,930.98	0	292.9238	7,747.99
2018	62,028.91	58,629.08	1,820.16	0	291.7759	7,374.14
2019	59,947.90	59,675.47	1,997.62	+1	293.4025	7,858.15
Mean	57,581.97	52,696.09	1,820.148	3.5	291.7107	6,826.605

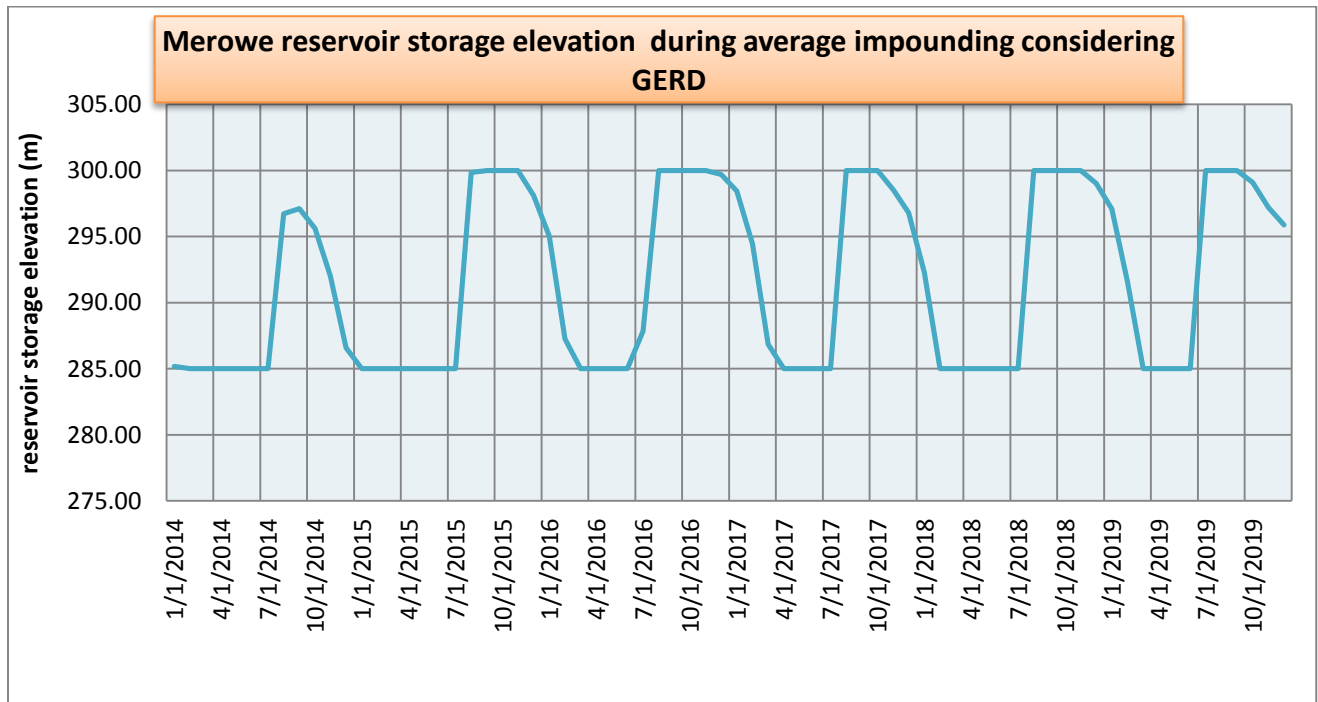


Figure 5-9 Merowe reservoir storage elevations during normal flow impounding scenario

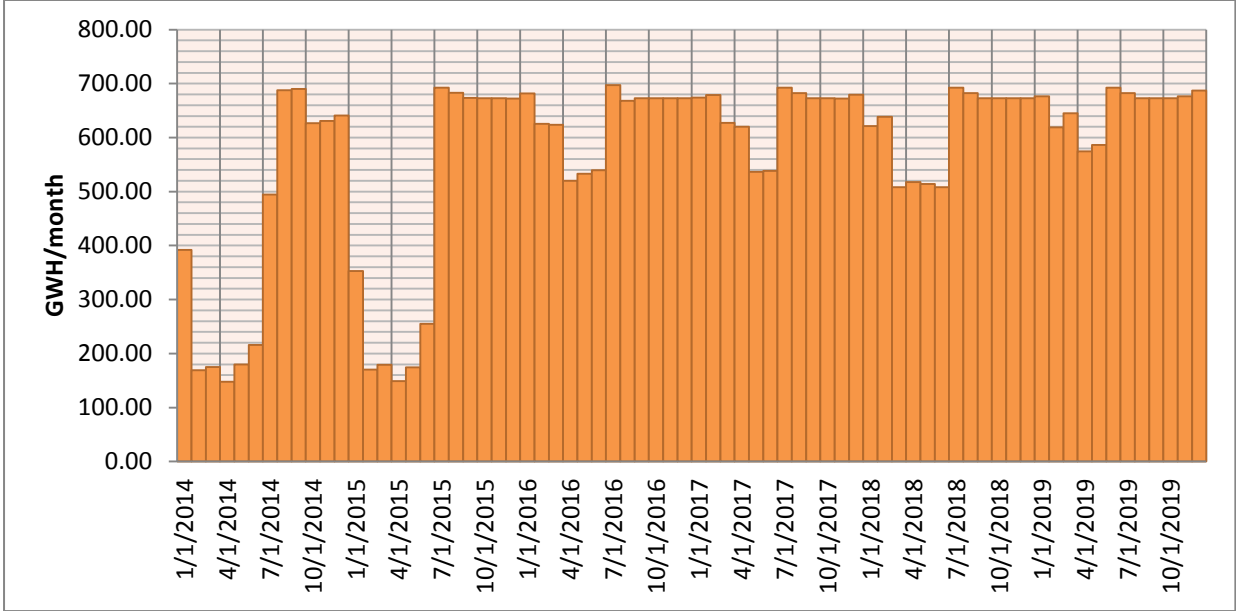


Figure 5-10 Monthly energy productions of Merowe during normal flow impounding

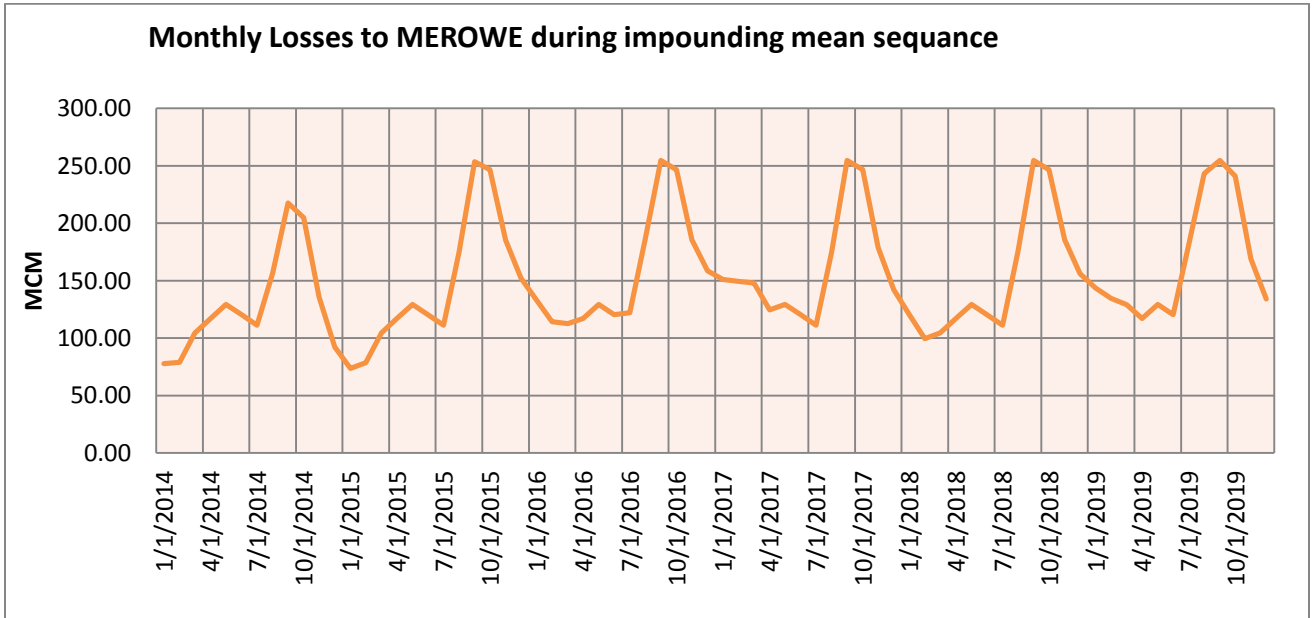


Figure 5-11 Monthly evaporation loss of Merowe during normal flow impounding scenario

▪ **High Aswan Dam**

Table 5.7 and figure 5.12 to 5.14 summarize HAD simulation results considering GERD upstream during its impounding periods. To summarize the results

- During average impounding the reservoir mean water level is 166.487 m and not lower than the minimum operating level 163m throughout simulation periods.
- Mean annual inflow- outflow of HAD during impounding periods will be respectively, 52,215 MCM of mean annual inflow and 52,441MCM is mean annual outflows.
- The mean annual loss 9.082 BCM and the mean energy production during these impounding periods will be 7,462 GWH/year.

Table 5-7 HAD normal flow impounding scenario simulation results

year	Inflow	Outflow	Loss	Irrigation water use Shortage of Egypt	Elevation	Energy
	MCM	MCM	MCM	(%)	m	GWH/y
2014	39,550.25	49,669.53	11,077.84	-10.5	172.05	7,935.78
2015	38,985.75	51,451.73	9,285.69	-7.3	167.20	7,555.47
2016	58,571.33	51,653.97	8,789.62	-6.9	165.71	7,396.76
2017	58,841.93	51,813.42	8,594.37	-6.7	165.12	7,339.03
2018	58,148.40	51,994.38	8,445.02	-6.3	164.66	7,299.29
2019	59,194.78	52,064.43	8,302.75	-6.2	164.18	7,248.46
Mean	52,215.41	51,441.24	9,082.548	-7.35	166.487	7,462.465

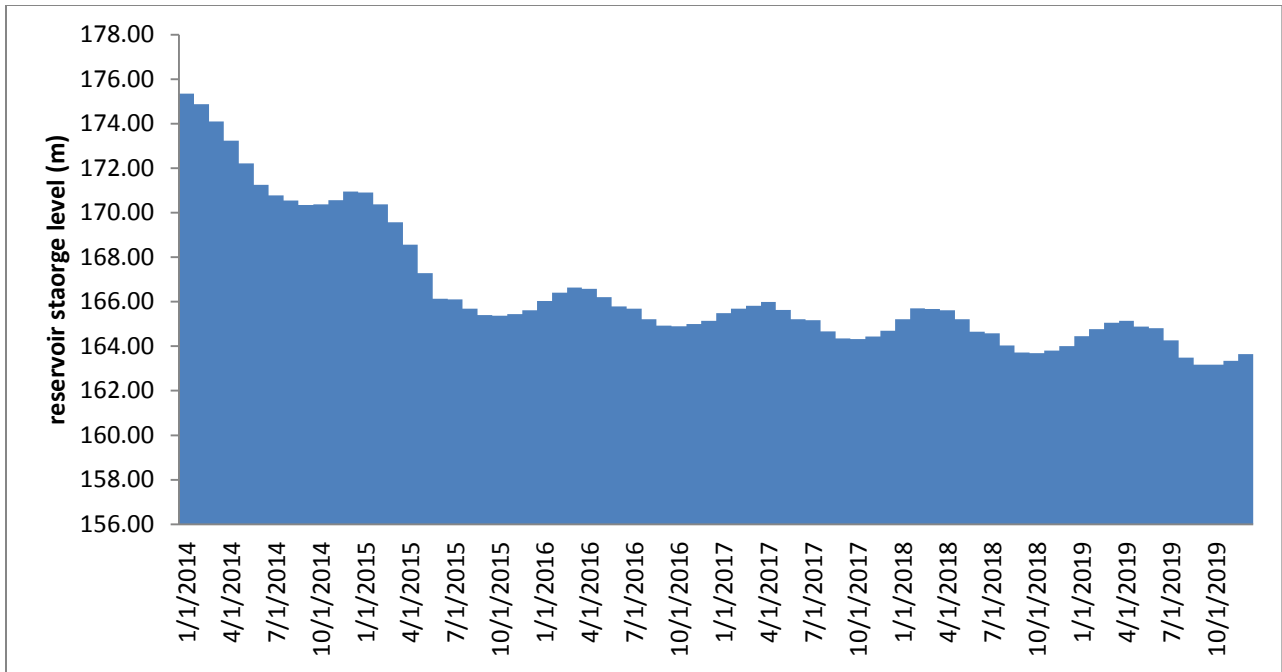


Figure 5-12 HAD reservoir storage elevation during normal flow impounding scenario with mean sequence

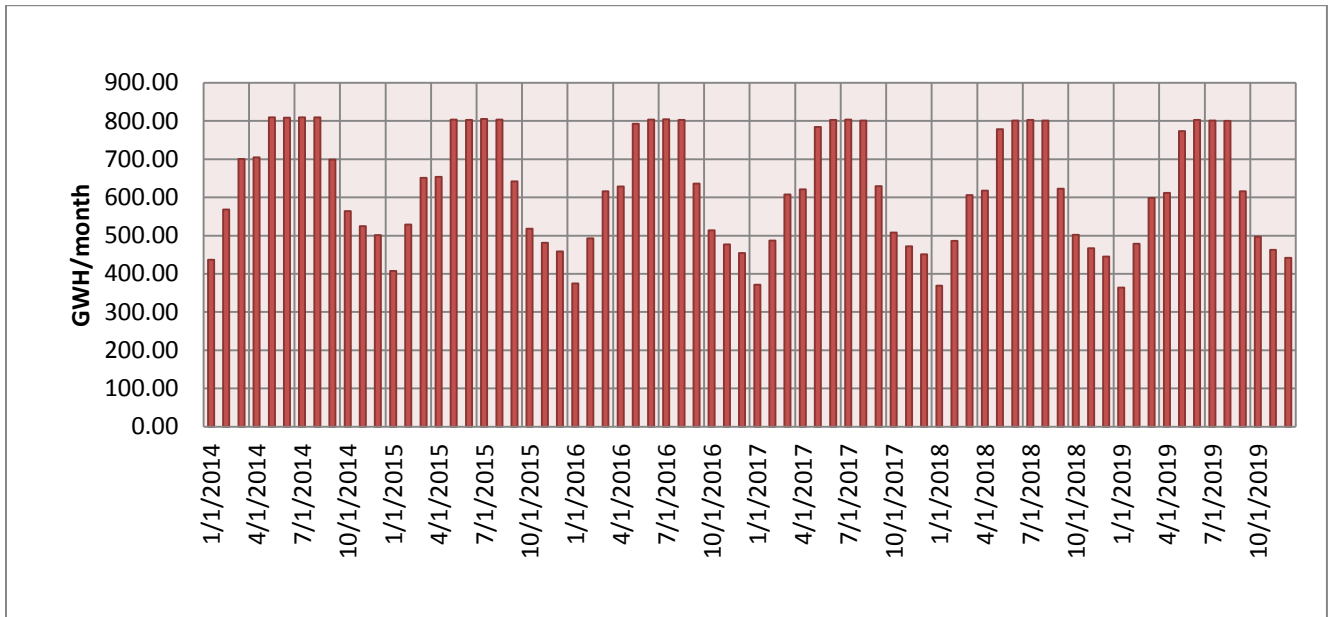


Figure 5-13 Monthly energy production of HAD during normal flow impounding with mean sequence

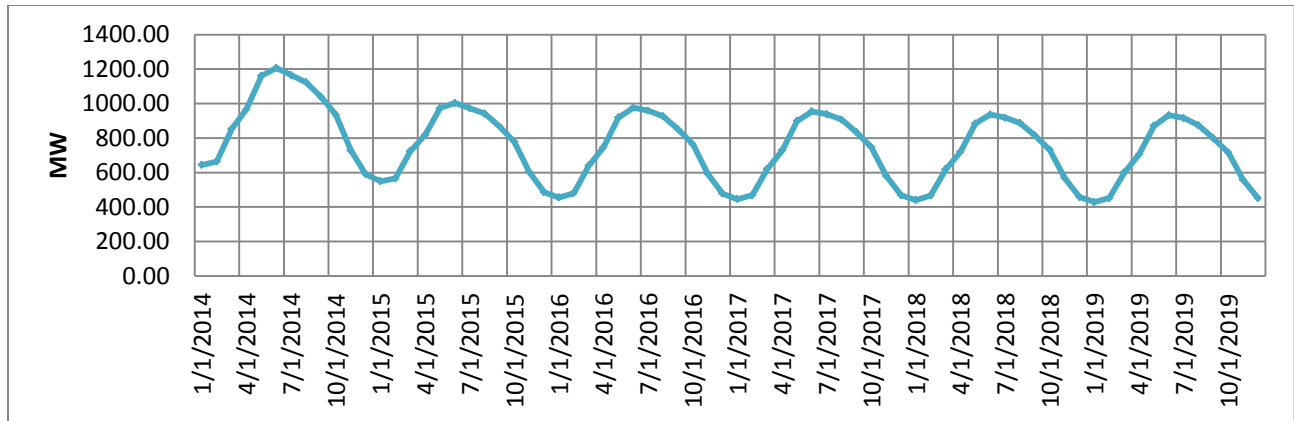


Figure 5-14 Monthly evaporation loss of HAD during normal flow impounding with mean sequence

5.2.3. 3rd scenario: - Dry flow Impounding Scenario

The dry flow impounding scenario considers an average sequence of 6 years flow at GERD in the basis of normal flow at HAD. The period of 6 years which presents the closest mean value to the average HAD naturalized inflows value on the whole available period has been selected.

- 2014 – 2019 flows will be equal to 1983 – 1988 flows from the available inflow series. It corresponds to the sequence of average years.
- This scenario has been considered if the Ethiopian 1985 drought will happens now in impounding phases. This is the rare scenarios ever happen in the filling periods.

➤ Results

▪ GERD

- Considering dry sequence of years from a hydrological point of view, GERD will reach mean annual reservoir storage elevation of 624.82 m.
- Yearly mean annual GERD inflow-outflows during the impounding stage will be equal to 37,427 and 17,930 MCM respectively. Related to this the yearly losses are 1.657 BCM.
- Energy generation will be limited during the impounding stage, the mean yearly values is 5,773 GWH/year.

Table 5-8 GERD dry flow impounding simulation scenario stage – yearly inflows, losses, outflows and energy generation simulated

year	Inflow	Outflow	Loss	Elevation	Energy
	MCM	MCM	MCM	m	GWH/y
2014	36,728.00	2,777.66	487.10	576.85	598.88
2015	45,941.00	7,736.20	1,468.04	620.28	1,722.18
2016	29,451.00	22,656.01	1,984.29	637.98	7,366.50
2017	41,435.00	18,113.48	1,991.36	638.13	5,819.96
2018	40,212.00	24,048.37	2,016.68	638.46	7,996.15
2019	30,779.00	32,253.36	1,997.44	637.23	11,135.01
Mean	37,424.33	17,930.85	1,657.485	624.822	5,773.113

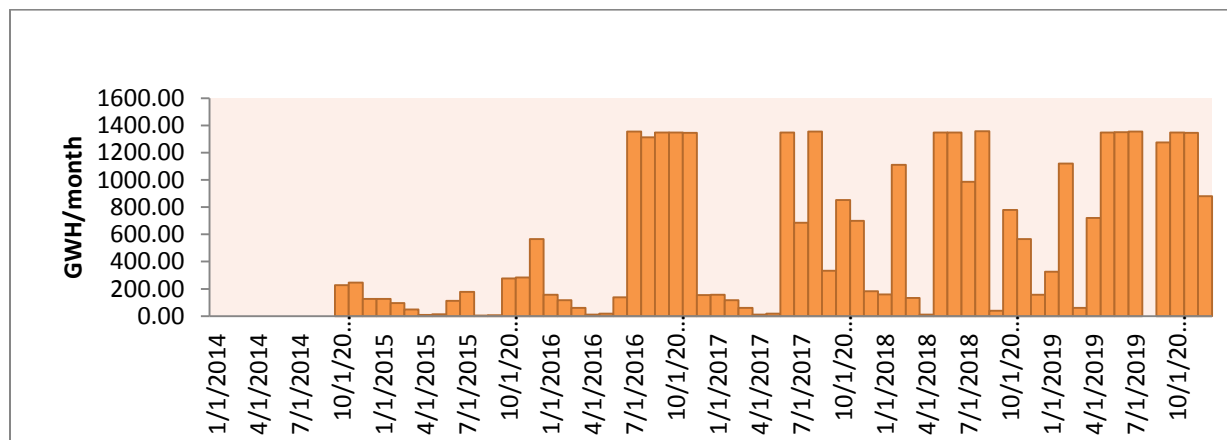


Figure 5-15 Monthly energy productions of GERD during dry flow impounding scenario

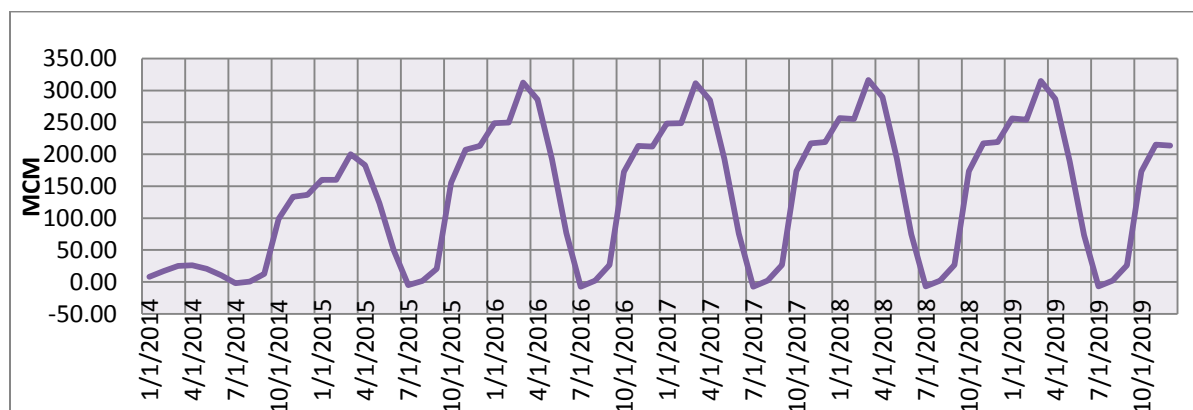


Figure 5-16 Monthly evaporation loss of GERD during dry flow impounding scenario

▪ **Merowe**

Table 5.9 and figure 5.17 to 5.19 summarizes Merowe simulation results considering GERD upstream during its impounding periods. To summarize the results

- During dry impounding the reservoir mean water level is 287.378m and not lower than the minimum operating level 285m throughout simulation periods.
- The Merowe mean annual inflow- outflow during impounding periods respectively, the average values of 44,957.94 MCM mean yearly inflow and 43,573.45 MCM is average yearly outflow.
- The mean annual losses of 1,429.677 MCM and the energy production during this impounding period is 5,181 GWH/year.

Table 5-9 Merowe dry flow impounding simulation scenario – yearly inflows, losses, outflows and energy generation

year	Inflow	Outflow	Loss	Irrigation water use Shortage of Sudan	Elevation	Energy
	MCM	MCM	MCM	(%)	M	GWH/y
2014	30,680.28	30,787.44	1,222.84	-36.4	285.05	3,593.25
2015	38,963.11	37,524.64	1,438.48	+3.3	287.45	4,522.14
2016	41,903.93	40,654.00	1,249.93	+6.6	285.43	4,532.75
2017	48,680.58	41,387.54	1,675.98	+6.8	290.45	5,434.62
2018	53,900.49	52,878.46	1,757.86	+0.6	290.88	6,658.00
2019	55,619.25	58,208.64	1,232.97	+0.5	285.01	6,349.20
Mean	44,957.94	43,573.45	1,429.677	-3.1	287.378	5,181.66

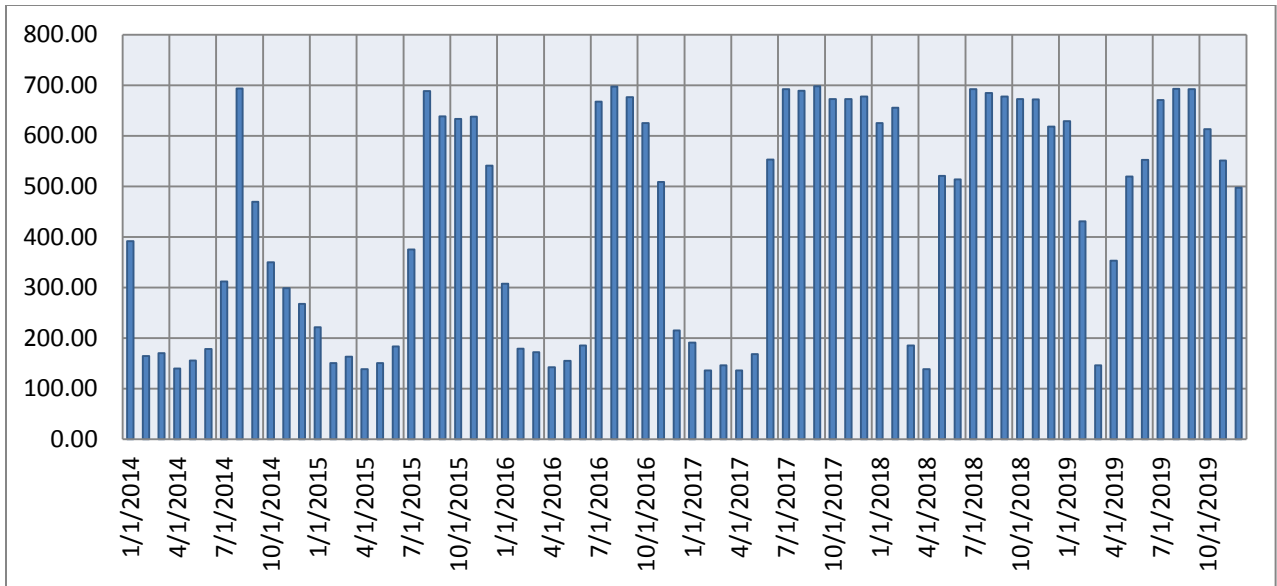


Figure 5-17 Monthly energy production of Merowe during dry flow impounding scenario

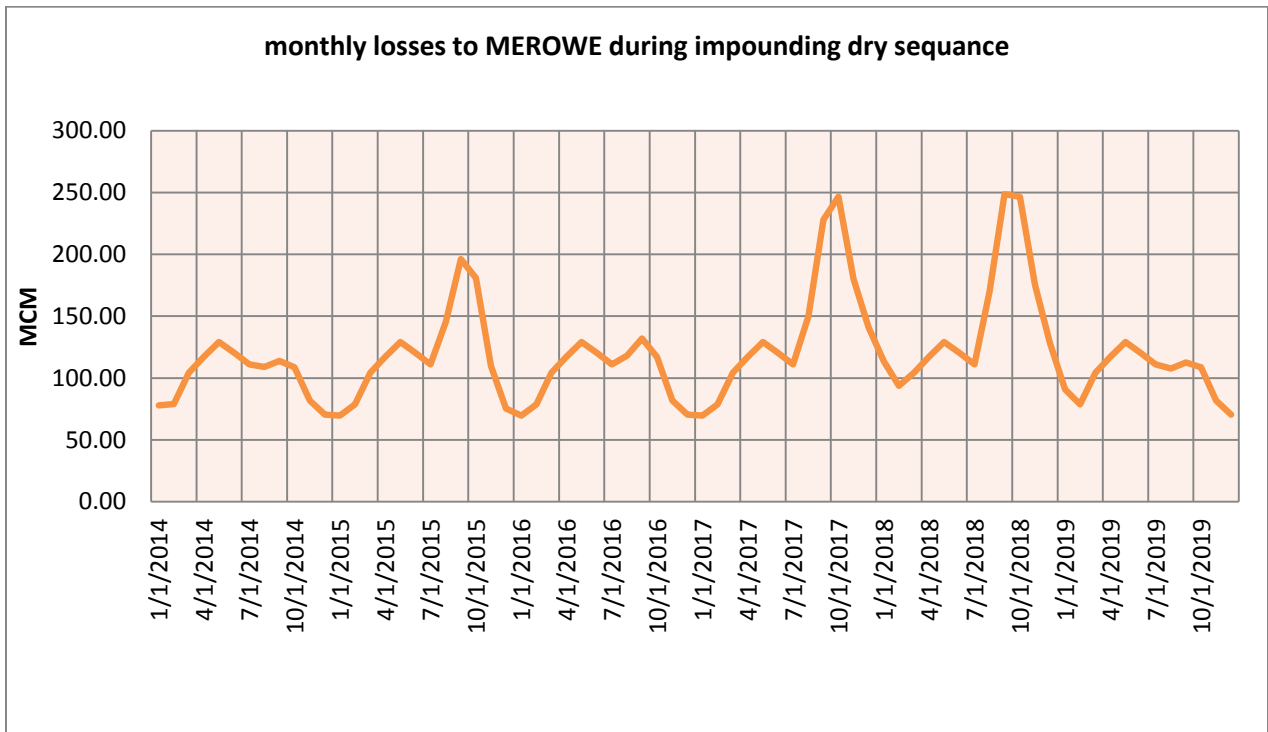


Figure 5-18 Monthly evaporation loss of Merowe during dry flow impounding scenario

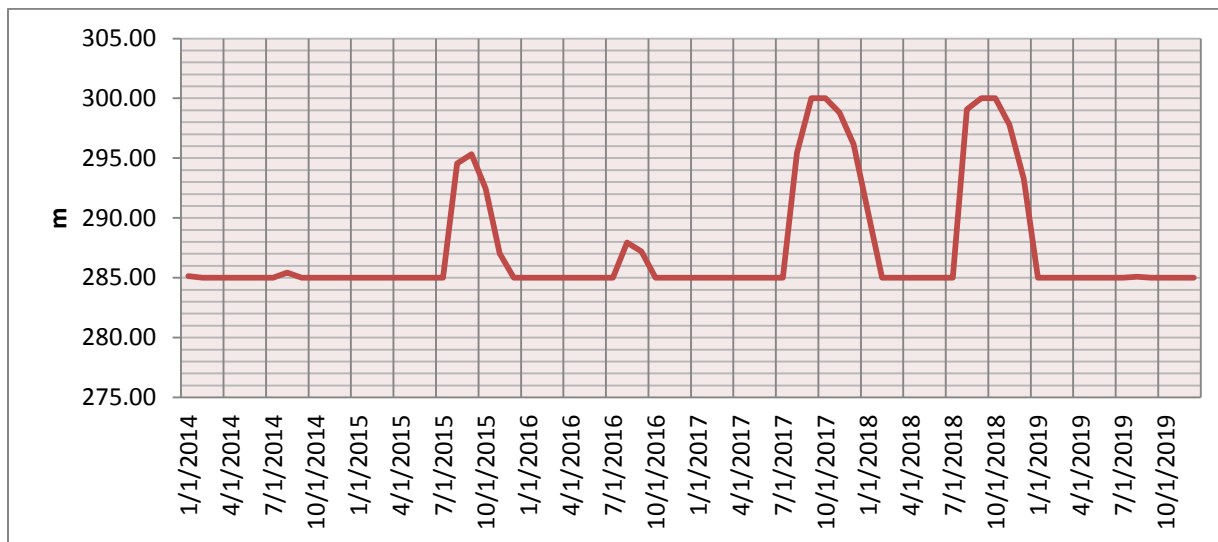


Figure 5-19 Monthly mean water level of Merowe during dry flow impounding scenario

▪ *High Aswan Dam*

Table 5.10 and figure 5.20 and 5.21 summarizes HAD simulation results considering GERD upstream during its impounding periods. To summarize the results

- During dry impounding the reservoir mean water level is 156.262 m and not lower than the minimum operating level 147m throughout simulation periods.
- The values of mean annual inflow are 43,093 MCM and 50,981 MCM is mean annual outflows results.
- The mean annual loss 6.406 BCM and the energy production during this impounding period will be 4,961 GWH/year.

Table 5-10 HAD dry flow impounding scenario simulation result of – yearly inflows, losses, outflows and energy generation simulated

year	Inflow	Outflow	Loss	Irrigation water use Shortage of Egypt	Elevation	Energy
	MCM	MCM	MCM	(%)	m	GWH/y
2014	30,306.76	49,734.66	10,945.50	-10.40	171.58	8,327.02
2015	37,043.96	52,728.11	8,190.88	-5.01	163.85	7,990.31
2016	40,173.32	54,873.55	6,255.63	-1.15	157.04	7,595.59
2017	40,906.85	50,597.39	4,479.62	-8.85	148.97	6,942.16
2018	52,397.78	47,883.43	4,255.54	-13.74	147.84	5,997.88
2019	57,727.96	50,070.81	4,310.78	-9.80	148.29	5,198.73
Mean	43,092.77	50,981.33	6,406.325	-8.16	156.2617	7,008.78

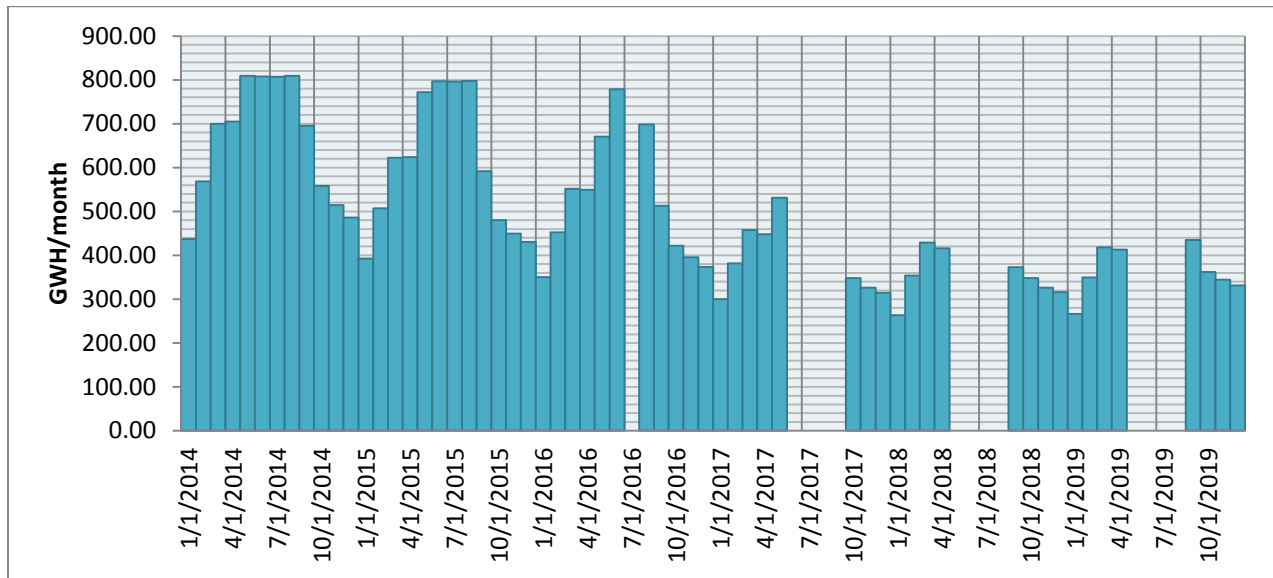


Figure 5-20 Monthly energy production of HAD during dry flow impounding scenario

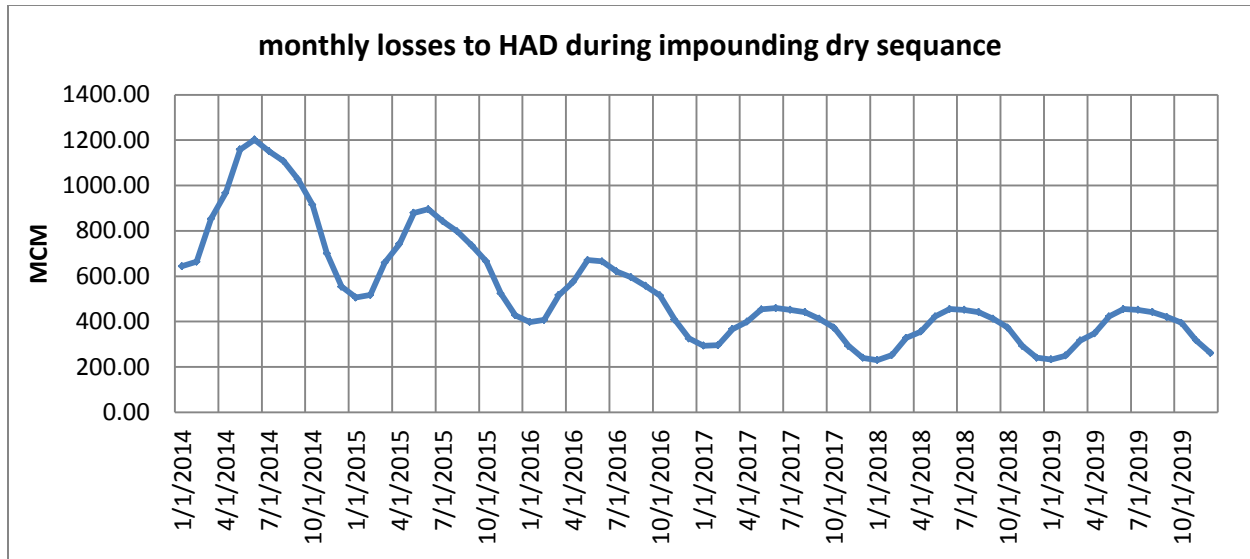


Figure 5-21 Monthly evaporation loss of HAD during dry flow impounding scenario

5.2.4. 4th Scenario: - long term future scenarios

➤ Results

▪ GERD

Operation simulations are obtained for the period January 2020 to December 2067 by using the hydrological data of January 1956 to December 2003 monthly inflow time series with a possible hydrologic pattern

As shown in Table 5.11 and figures 5.22 to 5.25:

- The average annual losses are equal to 1.719 BCM/year;
- During operation simulation periods the mean water level is 628.71 masl.
- Annual inflow is equal to outflow in addition to losses. This indicates GERD will provide regular pattern of flows for Sudan and Egypt. During the simulation periods GERD will produce 15,060GWH/year of energy for the country.

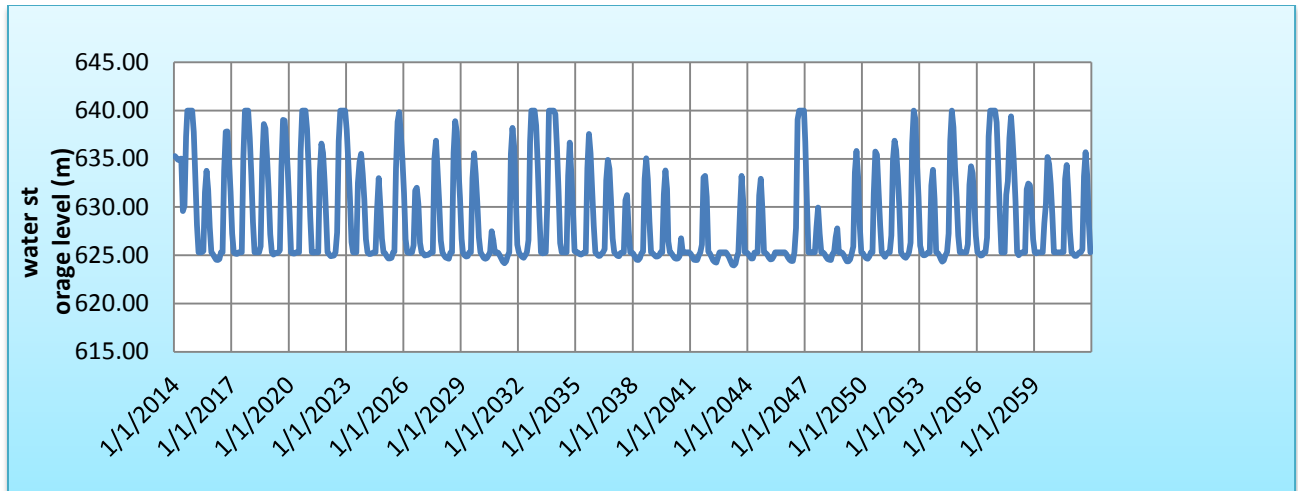


Figure 5-22 GERD monthly reservoir storage elevation during long term future scenario

Table 5-11 GERD long term scenario simulation results of yearly inflows, losses, outflows, mean water level and energy generation

Month	Inflow	Outflow	Loss	mean water level	total Energy
	MCM	MCM	MCM	m	GWH/month
January	878.31	3,639.64	216.82	627.76	1,165.14
February	532.25	2,607.88	212.45	626.32	794.61
March	453.50	1,592.94	261.83	625.40	441.58
April	469.83	624.60	237.97	625.13	148.13
May	663.25	378.61	160.42	625.22	54.87
June	1,877.96	1,664.80	63.67	625.34	507.87
July	7,904.02	6,841.49	-6.11	626.07	2,189.30
August	13,300.35	2,764.52	1.62	632.76	908.41
September	11,336.67	6,839.68	24.44	635.29	2,338.06
October	6,559.21	7,996.64	160.54	634.15	2,733.85
November	2,855.31	6,760.31	195.58	631.62	2,264.27
December	1,410.02	4,620.33	190.19	629.46	1,514.33
Year	48,240.69	46,331.46	1,719.41	628.71	15,060.43

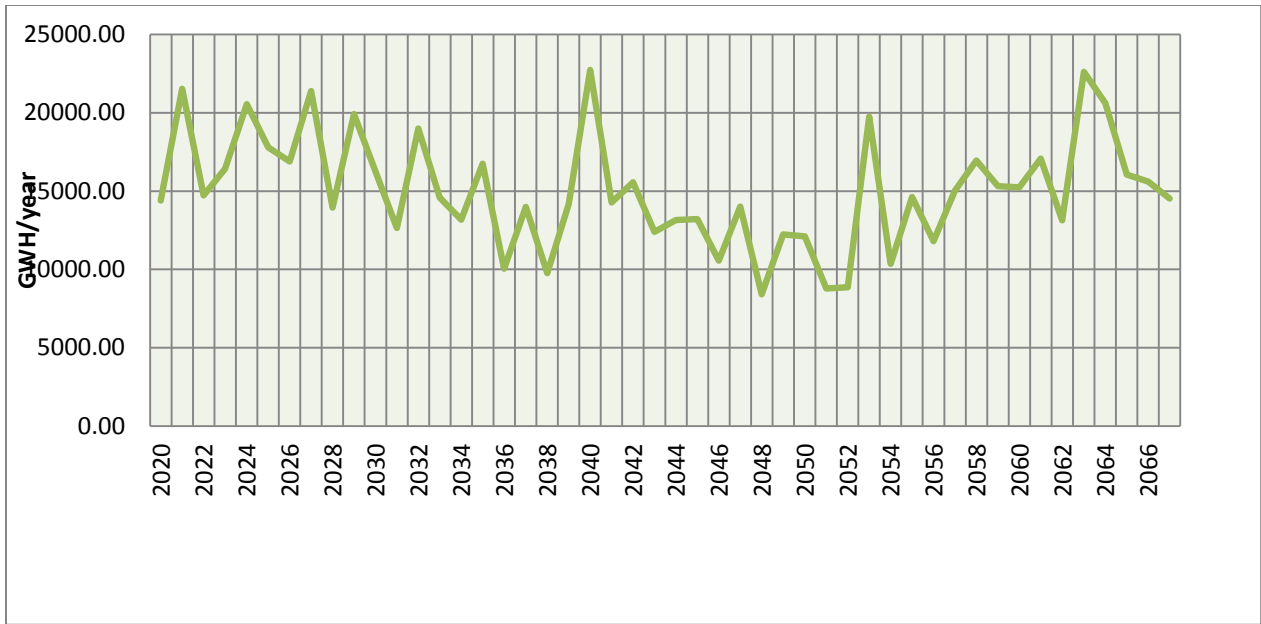


Figure 5-23 GERD monthly energy production simulation results during long term scenario

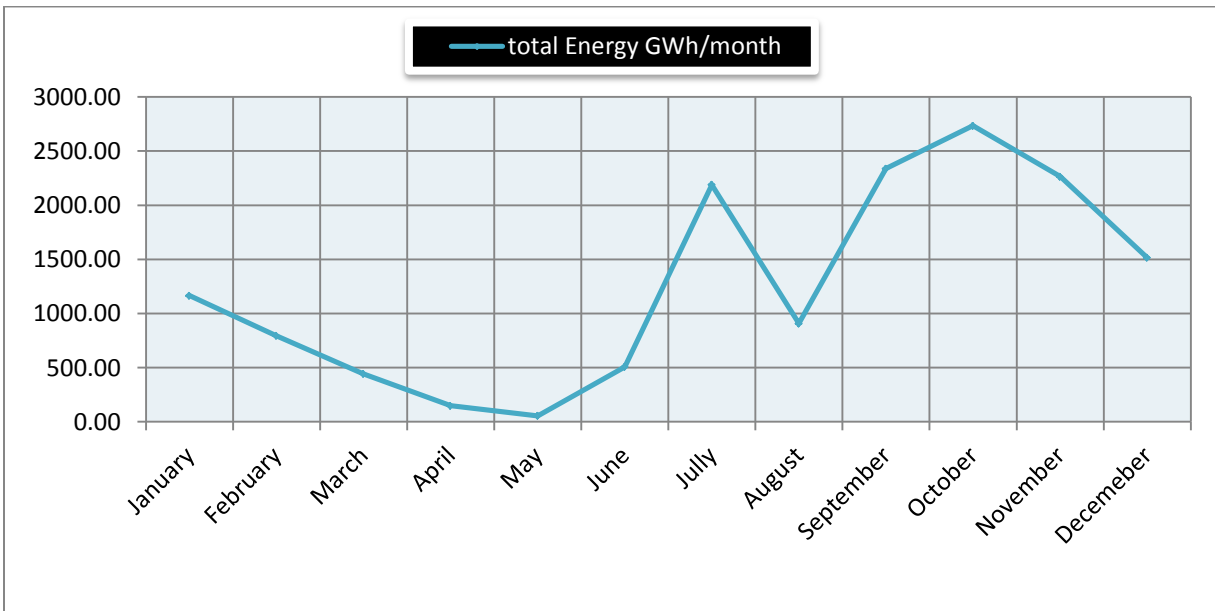


Figure 5-24 GERD mean monthly energy production results during long term scenario

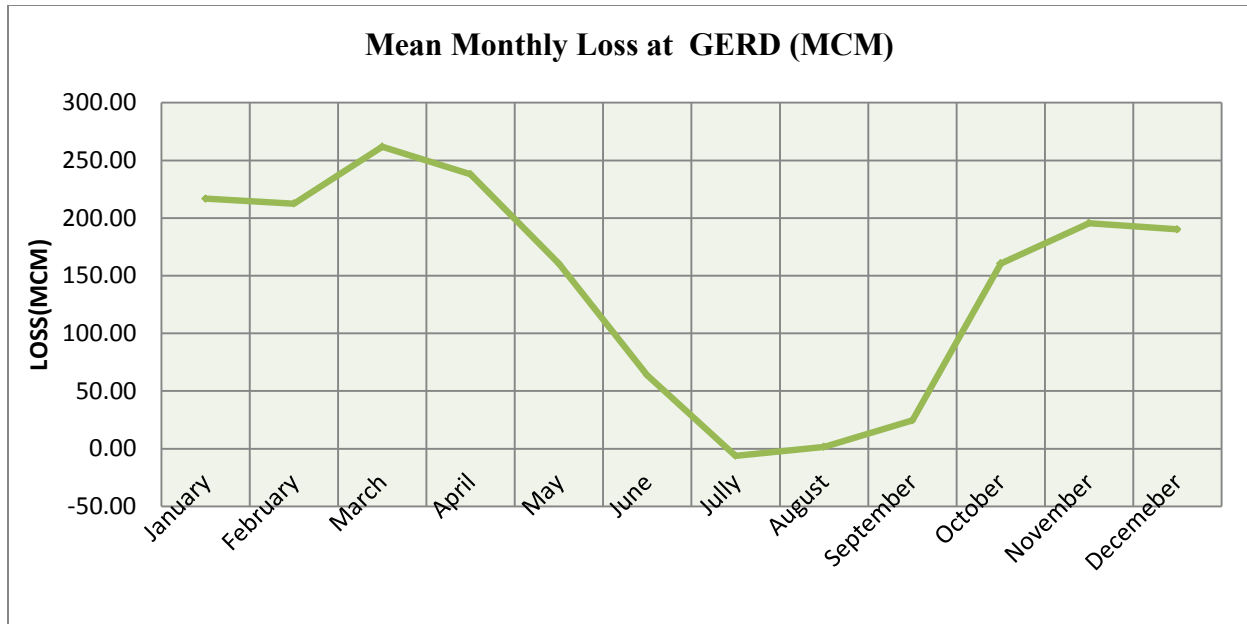


Figure 5-25 GERD monthly evaporation loss during long term future scenario

- **Merowe**

Merowe operation simulation results with and without GERD is taking a hydrological time series data and applying and allocating all irrigation water requirements of Sudan through a period of operation.

As shown in the Table 5.12 and figures 5.26 to 5.29; Without considering GERD the mean inflow and outflow to Merowe are 83,642MCM and 82,458MCM respectively which are equal considering the mean annual losses of 1211.1 MCM/year. The corresponding upstream GERD mean inflow-outflows are 81,489MCM and 80.252 MCM, respectively.

In the future Sudan energy production from Merowe hydropower reservoir will be raised up to 7,280GWh/y, by increasing 1,387 GWH/year from 5,893GWH considering upstream storage GERD.

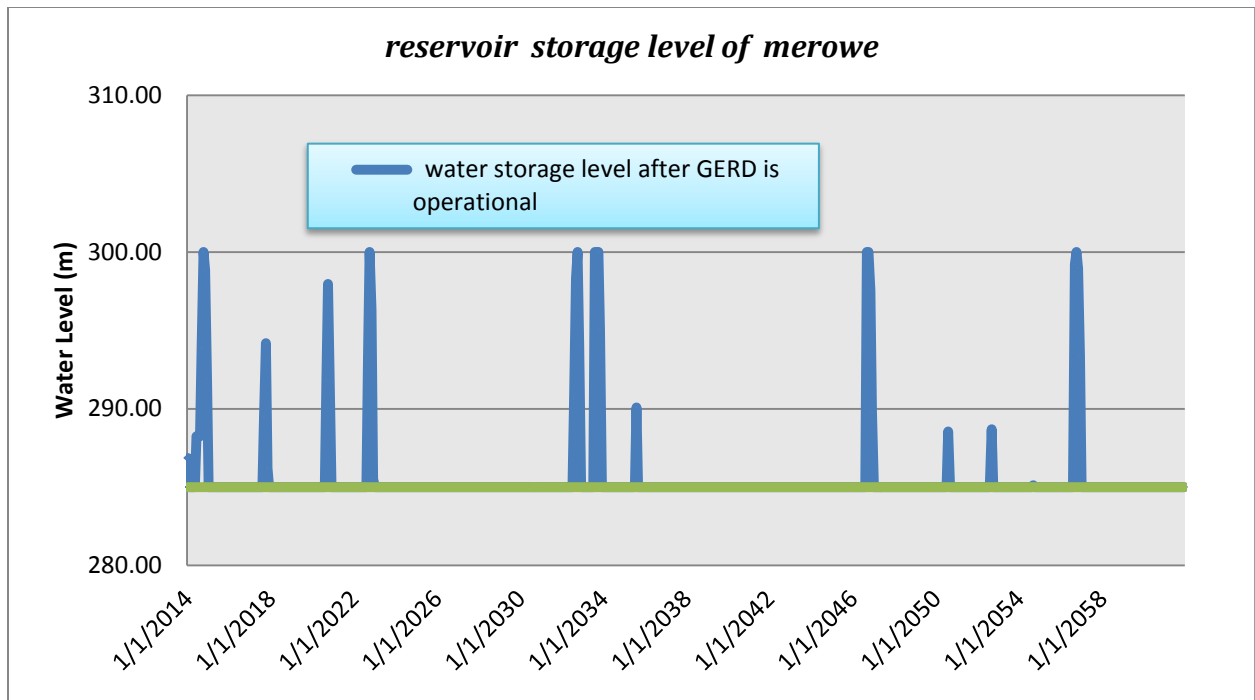


Figure 5-26 Merowe reservoir storage elevation during long term future scenario

Table 5-12 Merowe long term future scenario simulation results of yearly inflows, losses, outflows, mean water level and energy generation considering upstream GERD

Month	Inflow		Outflow		losses		Reservoir storage elevation		Mean Irrigation use Shortage of Sudan Considering GERD upstream (%)	total energy	
	Merowe alone	with GERD	Merowe alone	with GERD	Merowe alone	with GERD	Merowe alone	with GERD		Merowe alone	with GERD
Jan	2897.68	5631.65	2855.49	5816.18	69.90	71.066	285	285.04	+10	338.55	595.34
Feb	1806.06	3737.96	1727.47	3701.23	78.59	78.692	285	285.00	+36.40	205.85	372.05
Mar	1849.90	2920.66	1745.47	2840.21	104.43	104.430	285	285.00	+26.94	208.00	307.21
Apr	1783.32	1937.50	1666.15	1829.38	117.17	117.174	285	285.00	+22.06	198.57	207.35
May	2093.96	1809.32	1964.75	1683.08	129.21	129.210	285	285.00	+13.13	234.08	200.22
June	3345.48	3132.32	3225.12	2806.32	120.36	120.640	285	285.07	+0.43	380.99	343.13
July	11982.83	10920.30	11871.68	10809.92	111.16	111.674	285	285.07	0	922.48	918.03
Aug	22624.72	12088.88	22517.46	11700.94	107.26	110.288	285	285.68	0	657.20	930.00
Sep	16732.15	12235.17	16619.93	11460.17	112.22	123.468	285	285.87	0	900.00	900.00
Oct	9651.02	11088.46	9542.34	10694.49	108.68	127.332	285	287.34	0	855.90	910.55
Nov	5000.83	8905.82	4919.06	9289.46	81.77	94.943	285	286.63	+0.05	545.44	837.04
Dec	3874.32	7081.28	3803.88	7621.15	70.45	76.022	285	285.43	+2.69	446.78	759.31
Year	83642.28	81489.31	82458.79	80252.53	1211.2	1264.94	285.00	285.51	+9.31	5893.85	7280.22

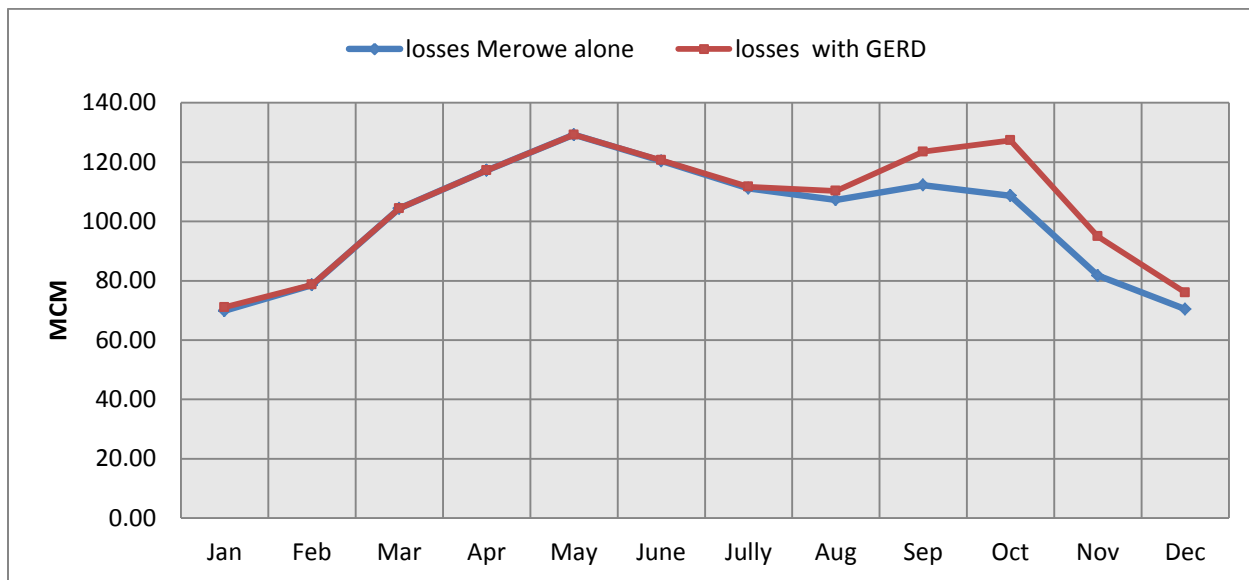


Figure 5-27 Merowe Mean monthly evaporation loss during long term future scenario

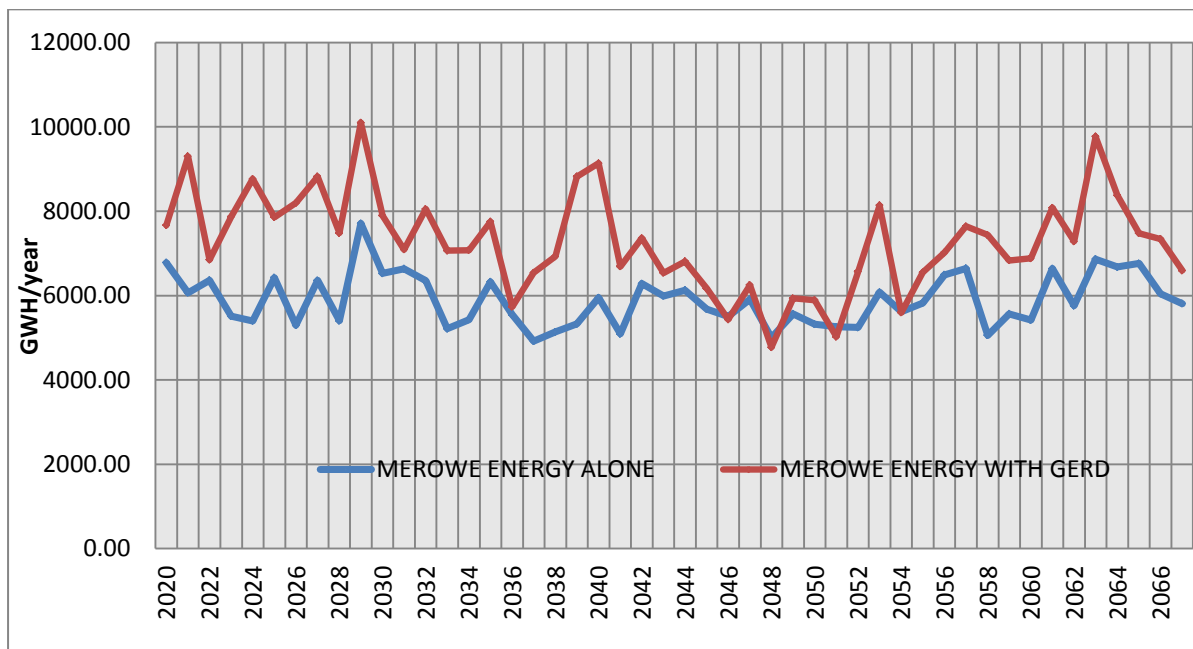


Figure 5-28 Merowe monthly energy production during long term future scenario

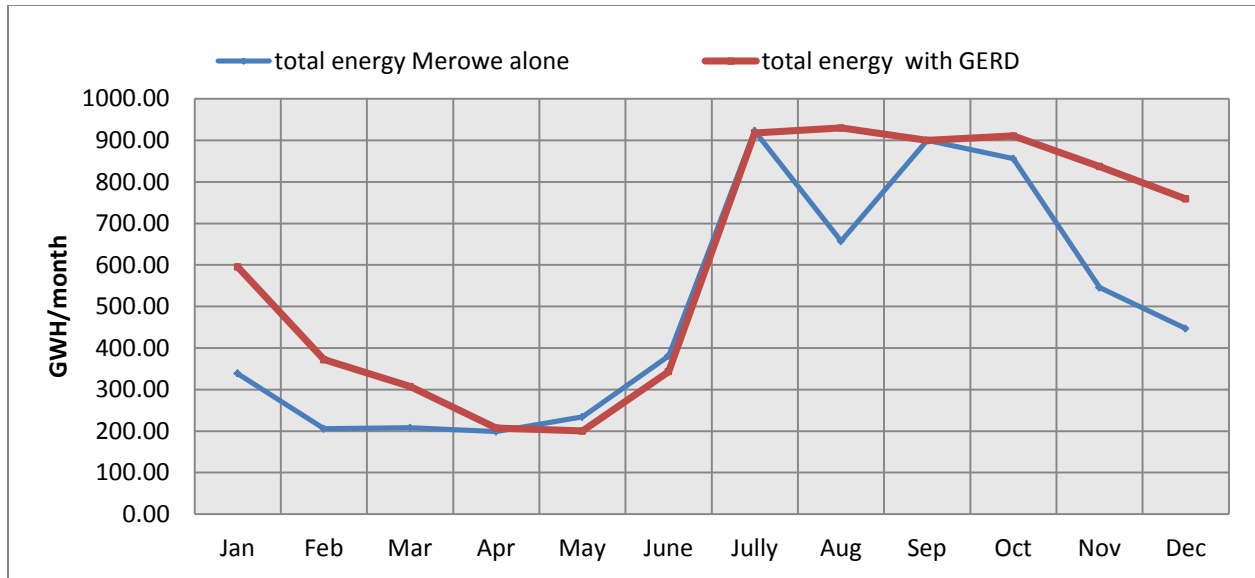


Figure 5-29 Merowe Mean monthly energy production during long term future scenario

▪ **High Aswan Dam**

Table 5.13 and Figures 5.30 to 5.34; HAD for the same periods of hydrological data like GERD and Merowe. Also all irrigation requirements satisfied in both simulation conditions that are without GERD and including GERD upstream of the rivers.

The inflow to HAD during simulation periods has yearly mean values of 81,978MCM which is without considering GERD and 74,719MCM with considering GERD.

However, the losses without considering GERD is equal to a mean values of 10.993 BCM and 9.957 BCM considering GERD. Also the reservoir mean water level during simulation periods which is not fall below the minimum operating level of 147m.a.s.l. So the loss is reduced by 1.036 BCM.

In the last the yearly total energy production is positively decreased from 8,747GWH/year to 8256.56 GWH/year due to the existence of upstream GERD.

Table 5-13 HAD long term future scenario simulation results of yearly inflows, losses, outflows and energy generation

Month	Inflow		Outflow		losses		Mean Irrigation use Shortage of Egypt Considering GERD upstream (%)	Reservoir storage level		total energy	
	HAD alone	with GERD	HAD alone	(%)	HAD alone	with GERD		HAD alone	With GERD	HAD alone	with GERD
Jan	2819.49	5726.31	2719.01	5320.69	560.24	553.94	0	175.98	175.71	469.90	738.49
Feb	1701.46	3649.08	3360.00	4458.39	580.73	576.72	0	175.55	175.43	575.00	376.87
Mar	1690.91	2761.67	4220.00	4686.84	776.97	775.84	0	174.92	174.91	710.44	750.56
Apr	1601.14	1755.32	4310.00	4454.23	899.03	899.75	0	174.2	174.91	717.44	430.37
May	1895.32	1610.69	5540.00	5540.00	1101.53	1001.48	0	173.18	173.12	898.46	894.20
June	3164.83	2923.68	7260.00	7260.00	1147.06	1044.81	0	172.03	171.92	876.39	469.18
July	11821.19	10758.14	7350.00	7350.00	1127.60	1019.31	0	172.72	172.39	878.58	576.47
Aug	22483.04	11646.67	7754.04	6330.00	1174.49	1020.06	0	175.4	173.27	992.51	907.84
Sep	16606.09	11411.20	11850.30	4741.17	1159.90	979.12	0	176.08	174.39	413.98	758.71
Oct	9529.94	10633.13	7817.18	4734.70	1052.80	903.35	0	176.19	175.3	931.73	729.49
Nov	4900.47	5241.28	4059.21	4379.45	795.69	675.36	0	176.18	175.68	693.87	858.19
Dec	3764.21	6602.40	3426.57	6361.39	616.61	507.12	0	176.1	175.78	589.45	765.88
Year	81978.11	74719.6	69666.31	65616.9	10992.65	9956.86	0%	174.88	174.34	8747.75	8256.25

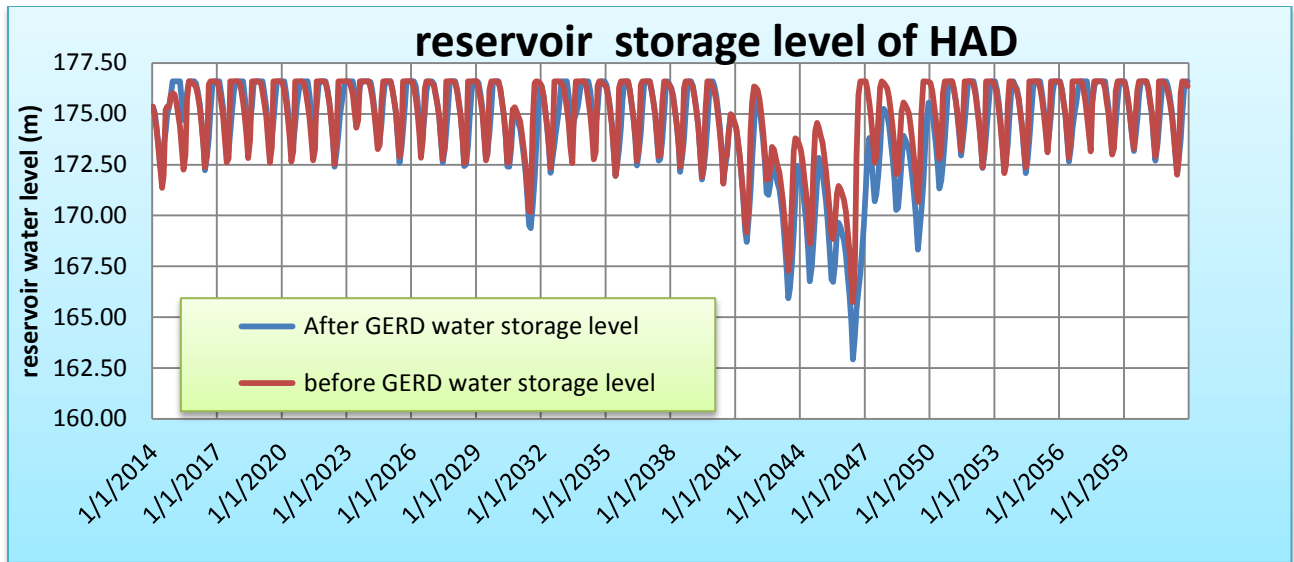


Figure 5-30 HAD reservoir storage elevation during long term scenario

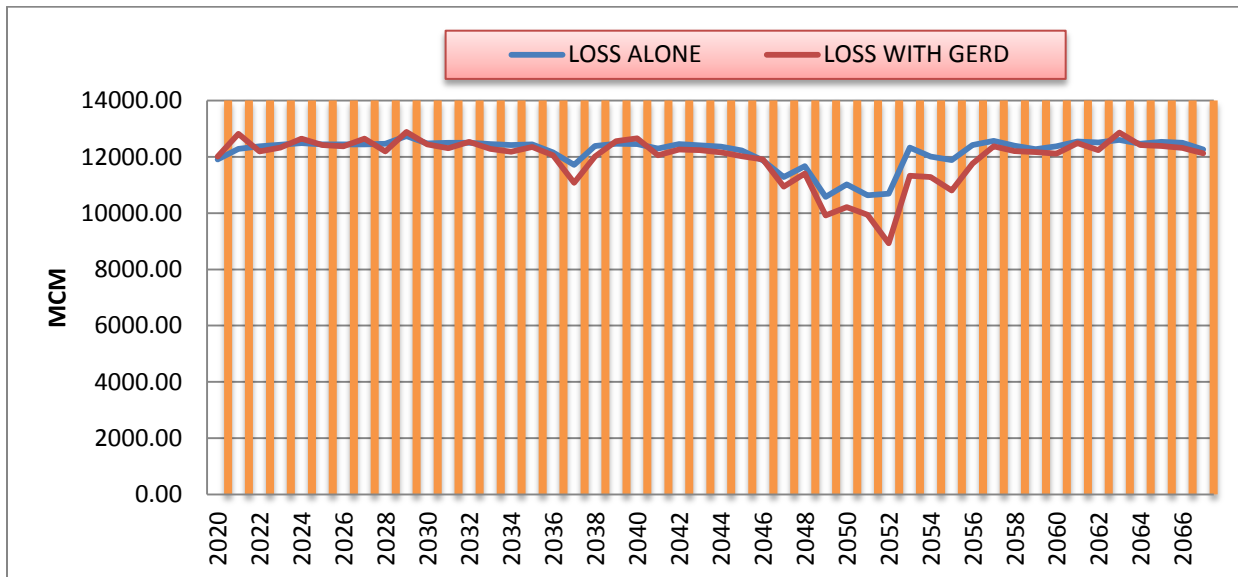


Figure 5-31 HAD monthly evaporation loss during long term scenario simulation

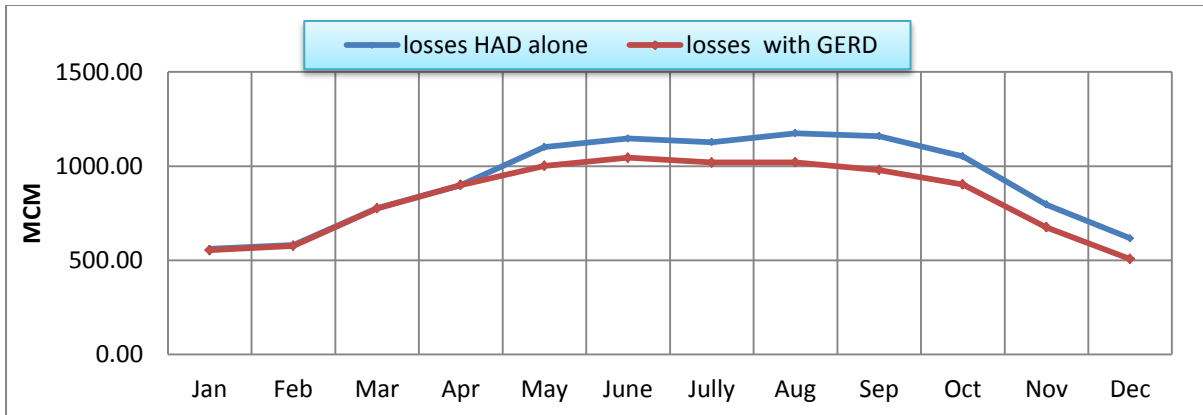


Figure 5-32 : HAD Mean monthly evaporation loss during long term operation simulation scenario

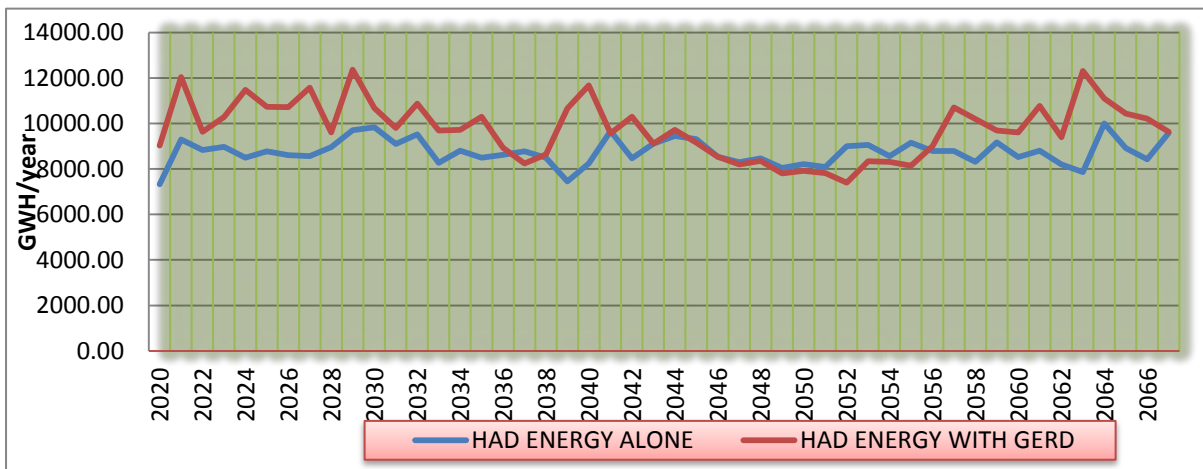


Figure 5-33 HAD yearly energy production during long term future scenario simulations

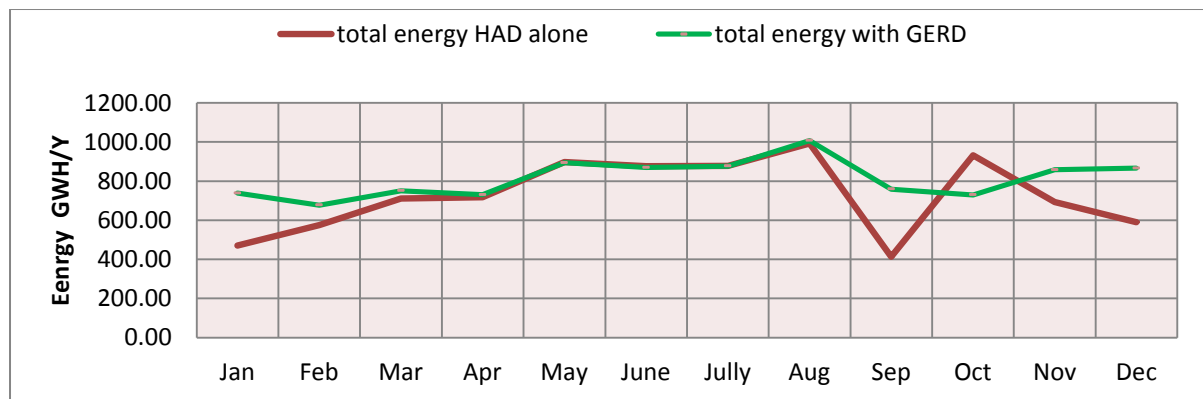


Figure 5-34: HAD Mean monthly energy production during long term future scenario

5.3 Discussions of the results

Simulation were undertaken to assess the potential impact of GRED on the downstream water uses on the eastern Nile river basin countries and their reservoirs, Merowe and HAD within four different scenarios.

From the tables and figures mentioned in the above and in the appendix shows the potential impact of GERD. This is assessed by using inflow, outflow, irrigation water demand, reservoir water losses and energy generation capacity.

i. Impacts

As shown in the table and figures during impounding periods the water level of both downstream countries and their storage reservoirs of Merowe and HAD fluctuates slightly .

- For the presence of upstream highland storages Sudan irrigation water uses have been decreased by of 3.5% and 3.1% respectively with impounding average and dry scenarios. In addition to irrigation water use, the energy generation during impounding – dry scenario decreases by 3.75% from the base line scenarios.
- The loss of reservoir water due to evaporation is slightly increased from the base line scenario. Merowe reservoir storage level increases for the existing of highland storage reservoirs.
- In the case of Egyptian, the energy production decreases by 12.3% during average and 16% during impounding dry scenario compared to the base line scenarios. Irrigation water uses decreased by 7.35% and 8.16% respectively with average and dry impounding scenarios.
- The energy production during long term scenarios decreased by 5.16% from the base line scenarios.

ii. Benefits

The benefit of GERD on downstream eastern Nile river basin countries and their reservoirs, Merowe and HAD is assessed based on the characteristics of the reservoirs and with 6000MW installed power generation capacity of GERD, it increases Ethiopian energy production by 15,060 GWH/year on the average, also it will increases the energy generation capacity of Nile basin countries.

- **Benefit for Sudan**

- During impounding average year scenario the energy will be increased by 25.23% from the same period of base line scenario.
- The reservoir storage elevation will not be affected by both impounding stage scenarios.
- .

- **Benefit for Egypt**

- The water losses during impounding average stage scenario will be reduced by 26.149% compared to the base line scenario. Also in dry scenario the losses will be reduced by 41.66%.
- During future scenarios the storage elevation of HAD not down below 147 m. Energy production capacity increase by 11.53% from 8747.85 GWH/years of base line scenarios. Also the there are no shortage on the irrigation water demand considering GERD.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

This thesis work attempted to model the evaluation of Great Ethiopian renaissance dam ,6000 MW GERD on the downstream water use sectors of eastern Nile river basin countries, Sudan and

Egypt respectively their biggest hydropower dam Merowe and HAD; By using MODSIM 8.1 river basin planning and simulation models. The river basin simulation has been carried out using 47 years average monthly inflow data, reservoirs physical characteristics' data, evaporation loss data and water demand data for irrigation, 18.5 BCM for Sudan and 55.5 BCM for Egypt.

Simulation of the river basin has evaluated by four different scenario such as Base line scenario, normal impounding scenario, dry Impounding scenarios and long term operational scenarios. The basic consideration of the simulation is to quantify the potential impact of great Ethiopian renaissance dam on the downstream countries and their water use sectors , Merowe and HAD both in energy production, reservoir evaporation losses, the reservoir storage elevation and water use for irrigation.

As a conclusion of a results during normal impounding scenarios compared to the base line scenarios

- Sudan energy production increase by 25.23% and HAD decreased by 12.3 %.
- HAD reservoir water storage elevation decreased by an average of 7.5m, where as in Merowe the reservoir does not fall the full supply levels.
- Irrigation water uses are decreased by 3.5% and 7.35% both in Sudan and Egypt respectively.
- Evaporation loss from HAD has decreased by 1.91 BCM in the other hand Merowe evaporation loss increased by 0.6 BCM.

During Dry Impounding scenarios compared to the base line scenarios

This scenario has been considered if the Ethiopian 1985 drought will happens now in impounding phases. This is the rare scenarios ever happen in the filling periods

- Sudanese energy production decrease by 3.75% and energy generation of HAD decreases by 16%.

- HAD reservoir water elevation fluctuates in the active zones through the simulation, where as in Merowe not to fall the full supply levels.
- Irrigation water uses are decreased by 3.1% and 8.16 % both in Sudan and Egypt respectively.
- Evaporation loss from HAD has decreased by 4.58 BCM in the other hand Merowe evaporation loss increased by 0.2 BCM.

For the Long term future operational scenarios compared to the base line scenario the results will be equal to this

- Energy production will be decreased by an average of 491.5GWh/year for High Aswan dam and increased 1,386 GWh/year for Merowe hydropower dam.
- Evaporation loss of reservoirs from had will decreased by 9.42%, and in case of Merowe it will increases by 4.44%.
- Irrigation water uses for both countries of Sudan and Egypt will not be affected due to the presence of GERD. In the other hand Sudan will have a surplus amount of water for their irrigation water uses increased by 9.31%.

As a conclusion the four scenarios with and without GERD the simulation result tells us; the construction of GERD in the upstream is advantageous to save the water loss due to evaporation for both eastern Nile countries. For the presence of GERD the eastern Nile power grid is increase by 15,060.43 GWH/year.

For this study Sudan has an advantageous both on the energy production capacity and the irrigation water uses. And in cases of Egypt during the impounding periods the irrigation water uses decreased slightly for this case trying to cultivate less water consumptive plants is the ultimate solution.

6.2. Recommendation

This work can be expanded in various ways to show the potential benefits of GERD on the downstream riparian countries, to involve the climate, hydrology, and water re-sources components as outlined below:

- Expand the reservoir operation assessments to include more demand, climate change and sedimentation flow.
- Study the impact of the integrated management of the constructed reservoirs on Sudan, Blue Nile River, and its impact on the high Aswan dam.

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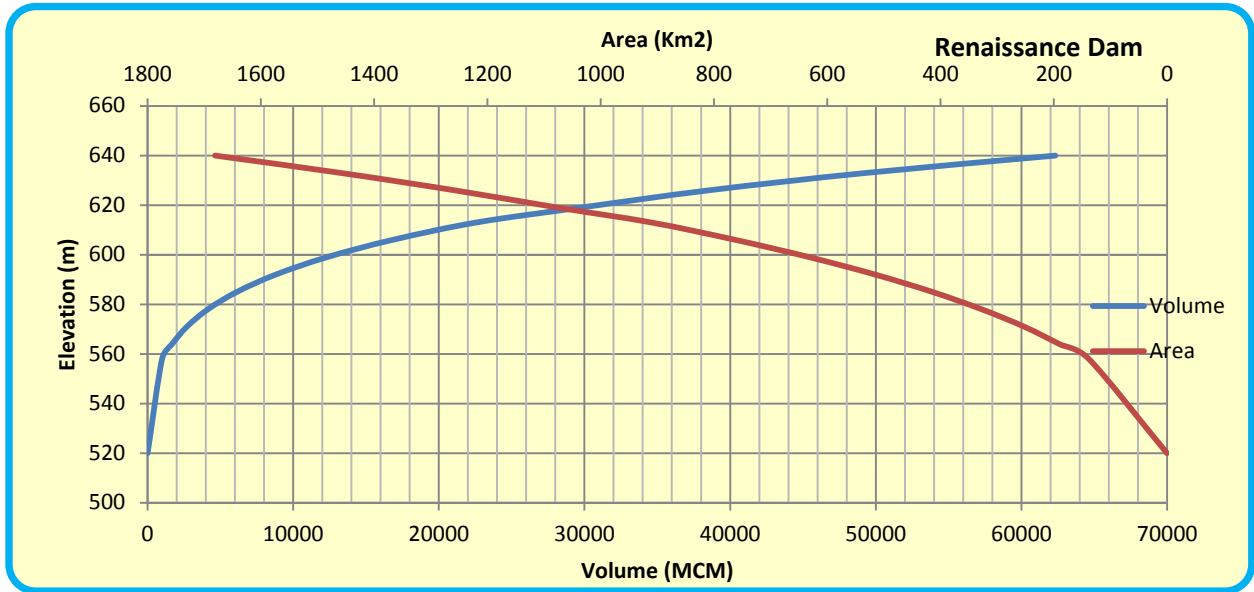
APPENDIX

Appendix 1- Hydrological data

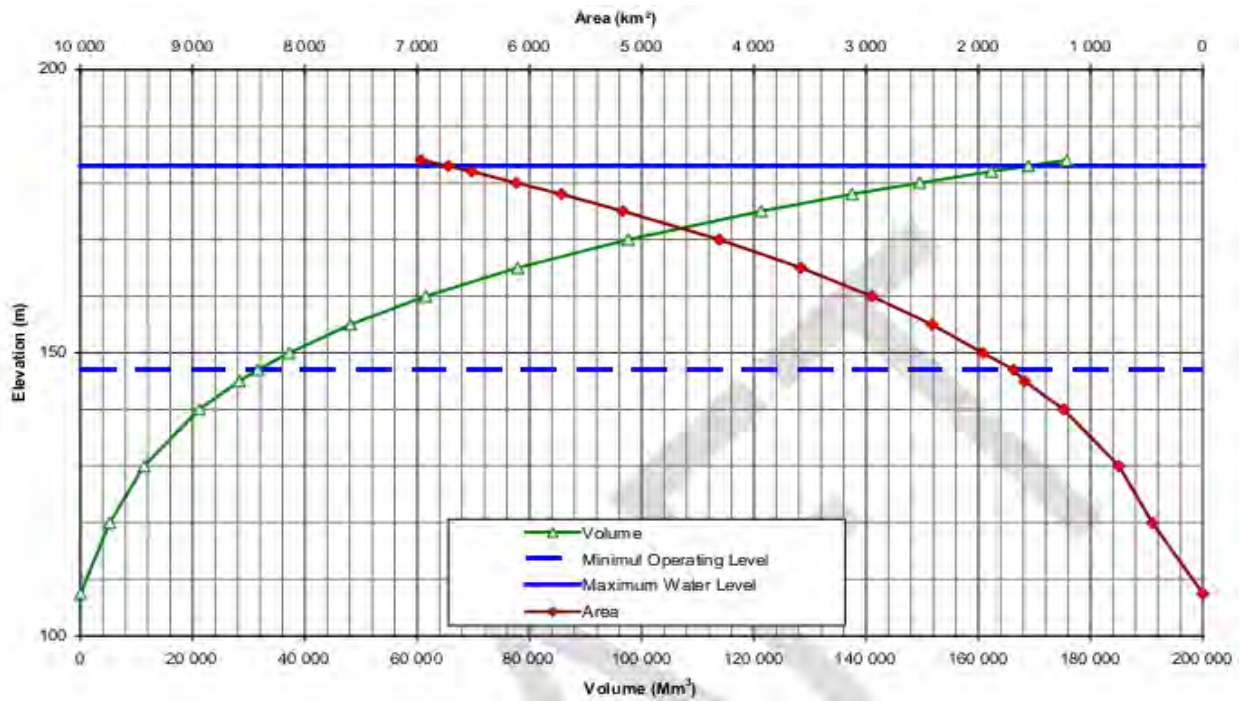
Appendix 1- 1 Statistical value of stream flow data of Nile River (from Conye study)

BASIN	Natural HAD INFLOW					Sudan Irrigation Deducted HAD inflow					Abbay (Border at Sudan)				
	Mean	STD	CV	MIN	MAX	Mean	STD	CV	MIN	MAX	Mean	STD	CV	MIN	MAX
PAR.															
JAN	3550	713.7	5.0	2328	6624	2822	707.3	4.0	1516	5811	925	222.8	4.1	551	1509
FEB	3282	651.9	5.0	2119	6164	2390	634.5	3.8	1284	5092	630	213.6	2.9	321	1237
MAR	2831	437.7	6.5	2082	4595	1763	397.0	4.4	1149	3459	465	166.1	2.8	234	856
APR	3160	431.7	7.3	2423	4817	2017	371.0	5.4	1475	3541	463	200.5	2.3	177	976
MAY	3485	448.4	7.8	2586	4629	1954	312.1	6.3	1441	2961	700	305.0	2.3	257	1631
JUN	3646	637.9	5.7	1991	5409	1231	396.4	3.1	674	2590	2067	691.8	3.0	974	4460
JUL	6016	1969.2	3.1	3506	12942	3915	1986.2	2.0	1424	10835	7421	1897.6	3.9	4897	15599
AUG	15462	4823.7	3.2	4807	23600	13238	4754.7	2.8	2718	21511	14753	2204.9	6.7	9573	19271
SEP	18450	3688.4	5.0	10362	27021	16801	3671.3	4.6	8779	25439	11768	2355.6	5.0	7290	16558
OCT	13438	2988.4	4.5	8329	20465	12308	3111.2	4.0	7062	19198	6711	1986.4	3.4	3341	11810
NOV	7186	1607.4	4.5	4708	11820	6202	1631.6	3.8	3762	10667	2854	825.3	3.5	1287	4504
DEC	4622	680.8	6.8	3103	6045	3697	846.1	4.4	2039	6539	1566	462.9	3.4	632	2305
YEARIY	85127	12086.8	7.0	61869	118254	68338	12568.9	5.4	44810	100772	50322	7953.9	6.3	31527	69912

Appendix 2-Physical Characteristics Data of the Reservoirs

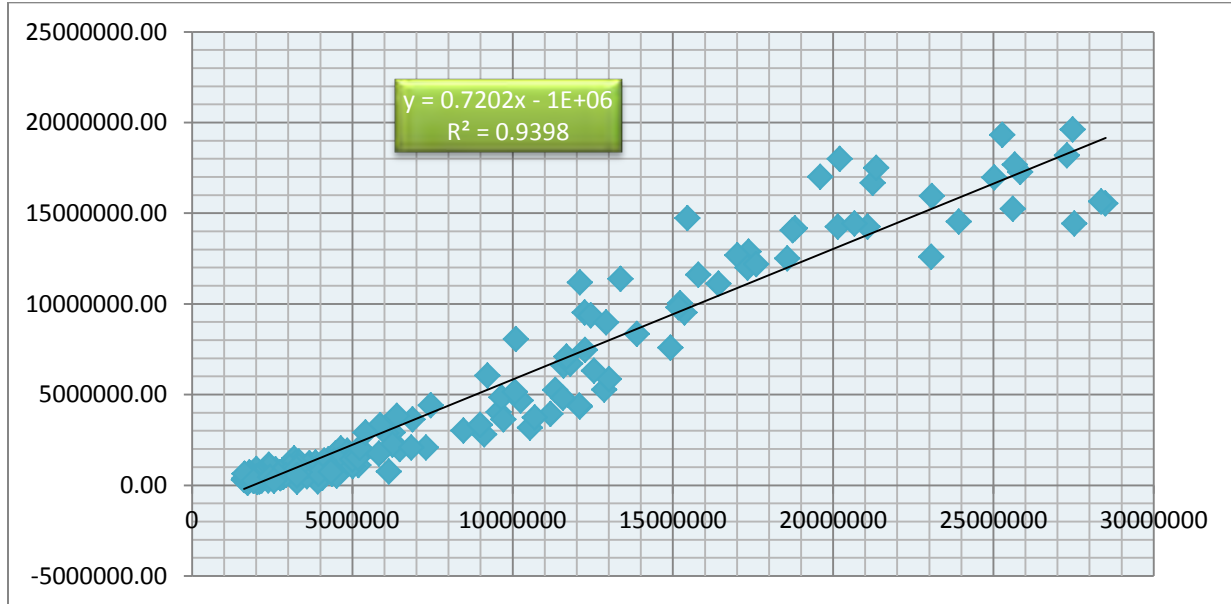


Appendix 2- 1 Elevation - Area - Volume curves at GERD (5250MW)

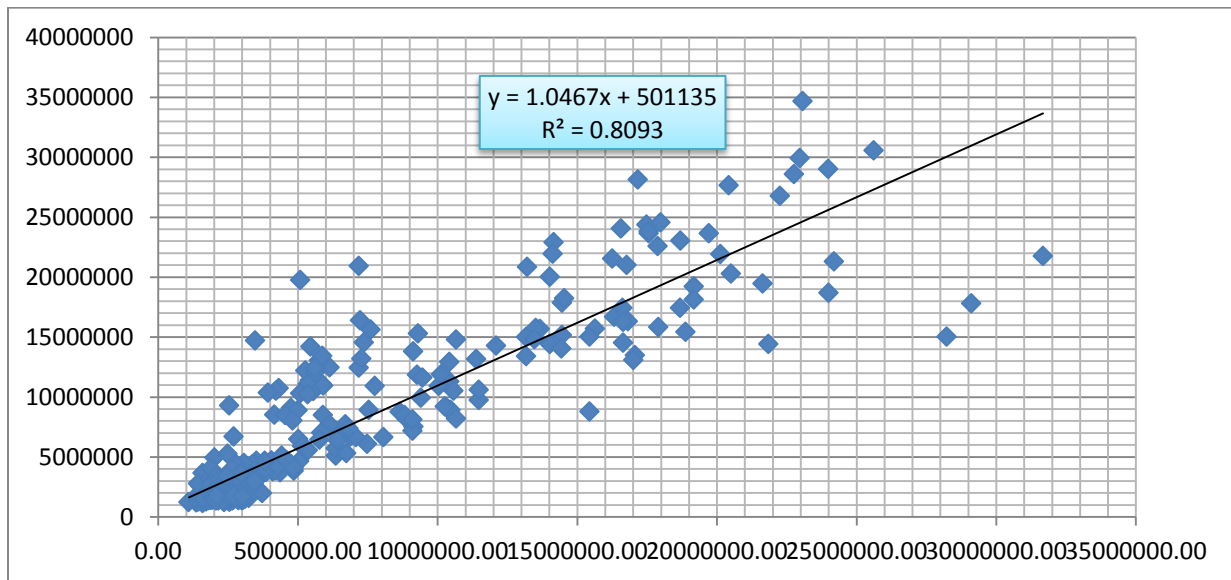


Appendix 2- 2 Elevation - Area - Volume curves at HAD (Tractebel Engineering Coyne et Bellier)

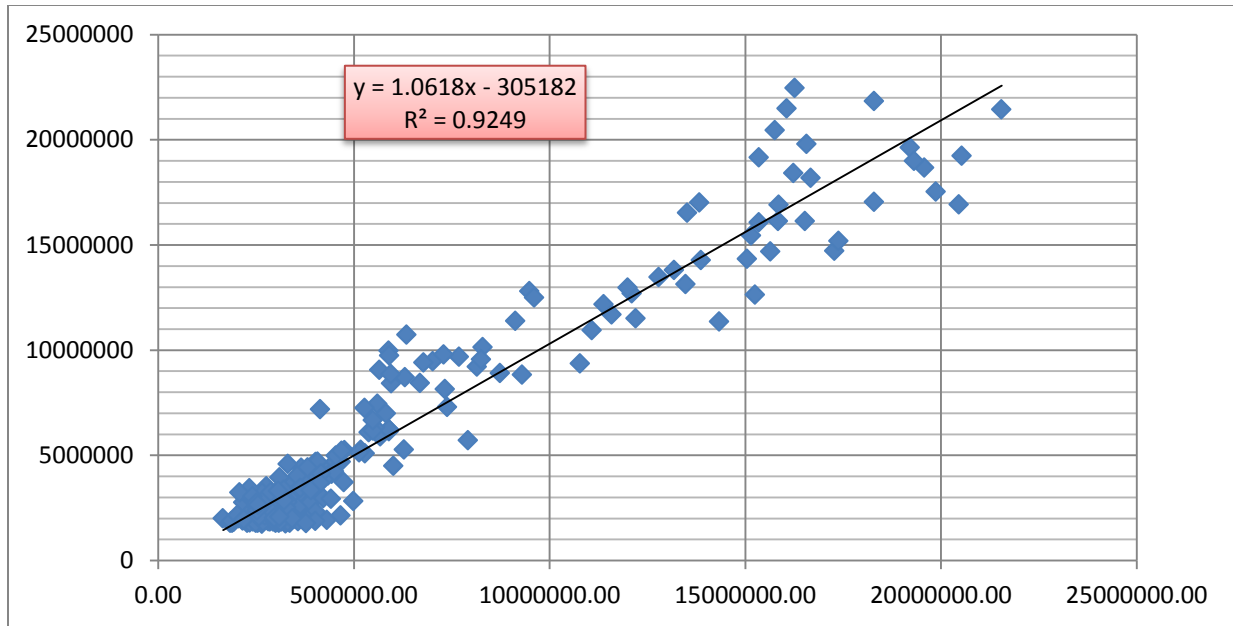
Appendix 3- MODSIM Modeling Calibration results



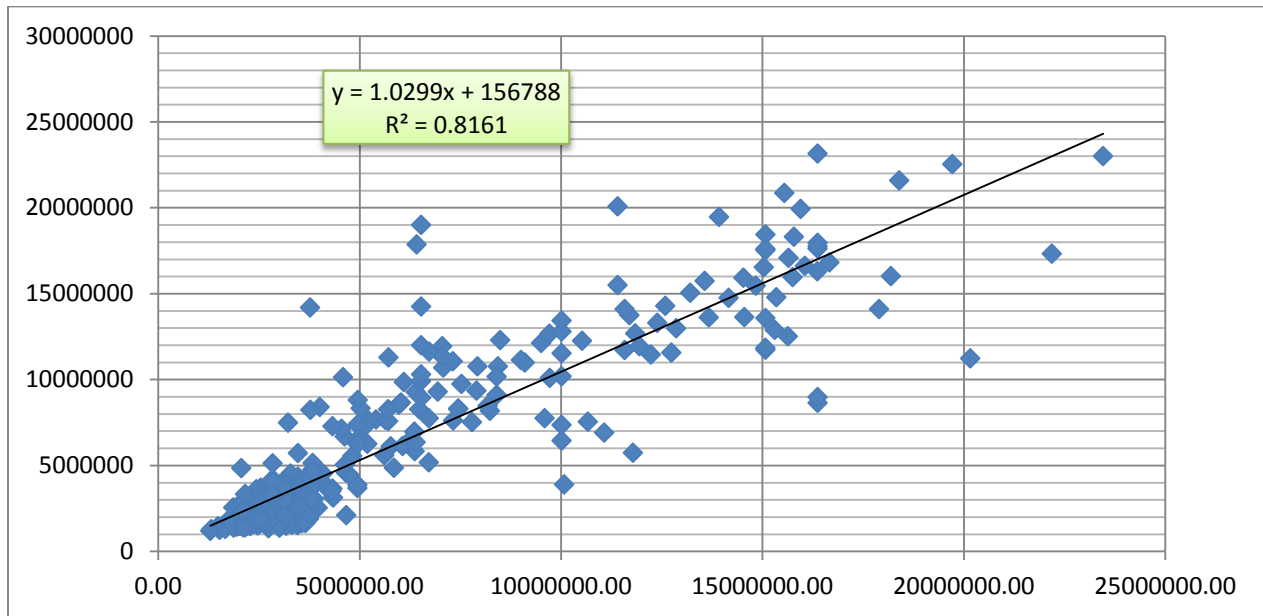
Appendix 3- 1 Simulated and measured inflow at Dongola (calibration)



Appendix 3- 2 Simulated and measured inflow at Dongola (validation)



Appendix 3- 3 Simulated and measured inflow at Tamaniat (calibration)



Appendix 3- 4 Simulated and measured inflow at Tamaniat (validation)

Appendix 4- scenario simulation results

Appendix 4- 1 Average monthly simulation results of Merowe during base line scenario

Year	Inflow (MCM)	outflow (MCM)	Evaporation loss(MCM)	Reservoir storage elevation(m)	Energy (GWH/year)
1956	93738.07	93849.24	1218.83	285	6781.75
1957	78669.96	77458.91	1211.03	285	6066.80
1958	92194.07	90983.04	1211.03	285	6364.38
1959	95605.03	94394.01	1211.03	285	5511.31
1960	91135.51	89924.48	1211.03	285	5399.06
1961	94773.44	93562.40	1211.03	285	6423.00
1962	96423.44	95212.41	1211.03	285	5297.65
1963	86884.05	85673.03	1211.03	285	6358.47
1964	99110.76	97899.75	1211.03	285	5402.08
1965	97299.25	96088.22	1211.03	285	7708.24
1966	80174.34	78963.30	1211.03	285	6526.12
1967	98618.52	97407.48	1211.03	285	6634.39
1968	78688.98	77477.95	1211.03	285	6350.07
1969	84280.36	83069.32	1211.03	285	5214.42
1970	89322.19	88111.15	1211.03	285	5431.10
1971	82868.56	81657.52	1211.03	285	6323.28
1972	59852.06	58641.03	1211.03	285	5548.15
1973	81640.01	80428.98	1211.03	285	4917.72
1974	93498.42	92287.39	1211.03	285	5138.98
1975	104621.71	103410.67	1211.03	285	5326.69
1976	81133.64	79922.60	1211.03	285	5947.60
1977	83265.27	82054.23	1211.03	285	5093.21
1978	84387.78	83176.73	1211.03	285	6282.62
1979	70870.51	69659.47	1211.03	285	5992.25
1980	81759.05	80548.01	1211.03	285	6127.48

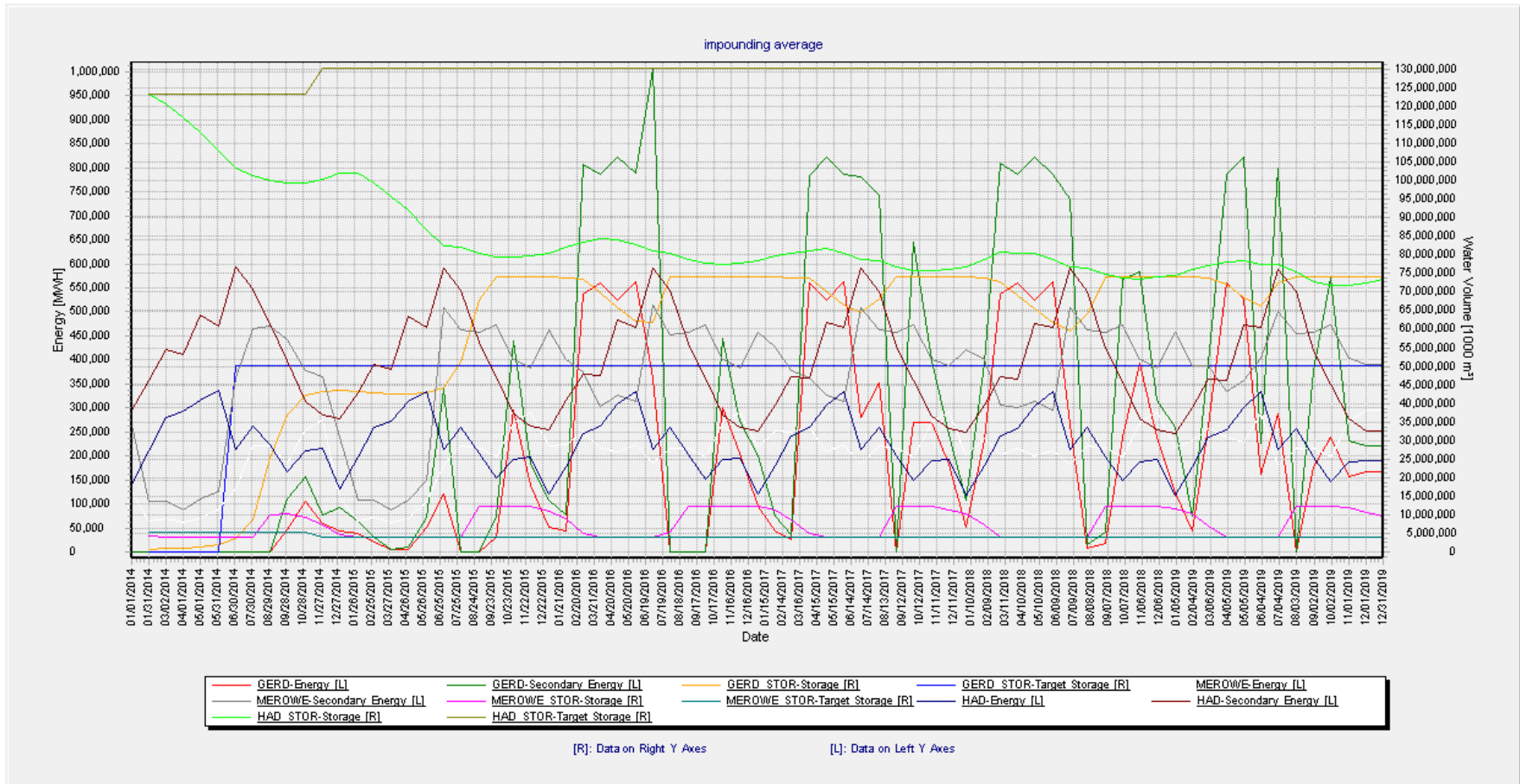
1981	74531.22	73320.18	1211.03	285	5680.90
1982	59834.32	58623.28	1211.03	285	5507.16
1983	77595.75	76384.71	1211.03	285	5912.40
1984	49510.49	48299.45	1211.03	285	5000.54
1985	72842.63	71631.60	1211.03	285	5567.41
1986	70143.99	68932.97	1211.03	285	5319.04
1987	54204.51	52993.47	1211.03	285	5258.44
1988	104368.66	103157.62	1211.03	285	5244.02
1989	70831.57	69620.53	1211.03	285	6077.01
1990	62723.84	61512.79	1211.03	285	5616.19
1991	80495.55	79284.51	1211.03	285	5824.86
1992	86538.27	85327.24	1211.03	285	6490.56
1993	91323.51	90112.47	1211.03	285	6642.46
1994	89737.67	88526.63	1211.03	285	5059.13
1995	73053.73	71842.69	1211.03	285	5565.99
1996	92259.50	91048.46	1211.03	285	5416.88
1997	87171.26	85960.23	1211.03	285	6640.17
1998	105892.66	104681.62	1211.03	285	5759.62
1999	97095.17	95884.13	1211.03	285	6861.86
2000	83761.60	82550.55	1211.03	285	6676.27
2001	90562.02	89350.98	1211.03	285	6761.77
2002	79577.74	78366.71	1211.03	285	6045.10
2003	79958.79	78747.76	1211.03	285	5810.09
Average	83,642.28	82,458.79	1,211.20	285	5,893.85

Appendix 4- 2 Average monthly simulation results of HAD during base line scenario

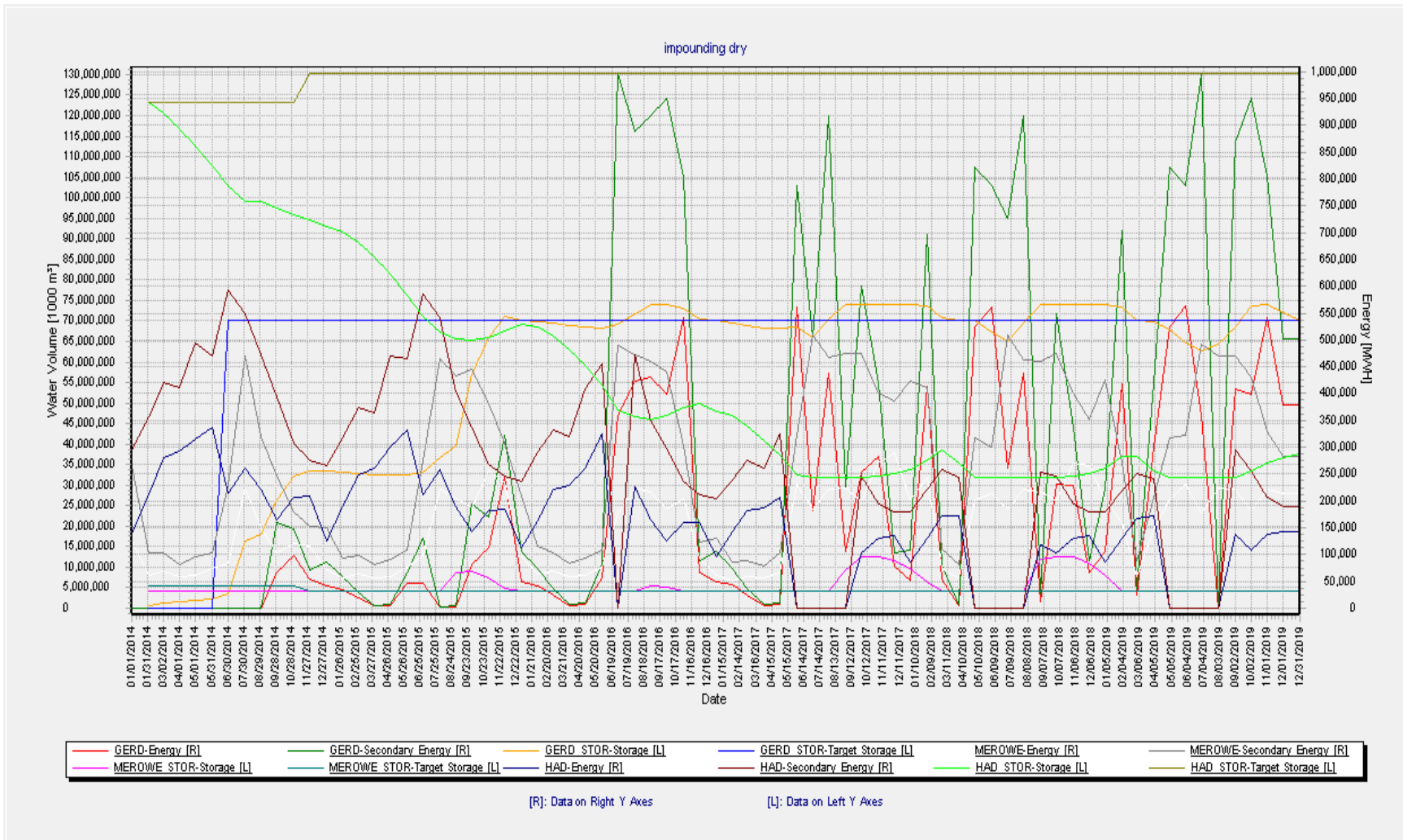
Year	Inflow (MCM)	outflow (MCM)	Evaporation loss(MCM)	Reservoir storage elevation(m)	Energy (GWH/year)
1956	93368.56	77756.67	11913.54	174.29	7329.61
1957	76978.24	62334.27	12283.60	175.11	9298.42
1958	90502.36	77187.30	12373.77	175.31	8828.51
1959	93913.31	81484.12	12429.19	175.44	8968.52
1960	89443.80	77005.60	12490.78	175.56	8498.78
1961	93081.71	80584.75	12444.37	175.46	8777.17
1962	94731.73	82320.46	12445.98	175.47	8610.64
1963	85192.34	72708.41	12449.21	175.47	8570.41
1964	97419.06	84955.82	12463.23	175.50	8961.93
1965	95607.53	82867.03	12740.50	176.06	9705.01
1966	78482.62	66006.08	12476.55	175.54	9833.66
1967	96926.80	84423.53	12503.26	175.59	9093.47
1968	76997.27	65038.70	12495.55	175.57	9519.00
1969	82588.63	69602.69	12456.13	175.48	8274.50
1970	87630.47	75203.35	12419.95	175.42	8805.26
1971	81176.84	68727.36	12449.47	175.49	8491.93
1972	58160.34	55510.00	12164.07	174.78	8625.50
1973	79948.30	59126.64	11720.17	173.91	8768.51
1974	91806.71	79578.43	12388.83	175.33	8496.28
1975	102929.98	89889.08	12468.11	175.49	7449.64
1976	79441.92	67965.81	12455.40	175.48	8235.13
1977	81573.55	68293.73	12300.53	175.17	9657.36
1978	82696.05	70237.73	12458.32	175.49	8461.75
1979	69178.79	58029.00	12414.83	175.41	9111.23
1980	80067.32	67027.22	12366.30	175.29	9446.67
1981	72839.50	61573.27	12222.29	175.00	9310.75
1982	58142.59	55510.00	11876.32	174.14	8528.56

1983	75904.03	55510.00	11288.37	172.99	8301.52
1984	47818.77	55510.00	11665.93	173.50	8461.22
1985	71150.92	55510.00	10579.15	171.08	8038.68
1986	68452.28	55510.00	11025.43	172.16	8207.48
1987	52512.79	55510.00	10635.54	171.06	8091.42
1988	102676.94	64291.00	10689.32	171.44	9000.81
1989	69139.86	57847.13	12335.68	175.26	9059.69
1990	61032.12	55510.00	12014.60	174.49	8570.09
1991	78803.82	59473.69	11889.60	174.27	9147.94
1992	84846.55	72333.26	12418.40	175.41	8791.19
1993	89631.78	77068.18	12563.61	175.70	8794.80
1994	88045.94	75933.45	12395.67	175.35	8310.38
1995	71362.00	60294.86	12272.87	175.10	9161.59
1996	90567.80	76701.78	12377.12	175.30	8523.04
1997	85479.54	72938.24	12541.31	175.66	8796.62
1998	104200.95	91690.55	12510.38	175.59	8201.54
1999	95403.44	82799.93	12603.51	175.77	7861.20
2000	82069.87	69608.05	12461.82	175.51	9998.42
2001	88870.31	76330.71	12539.60	175.64	8918.43
2002	77886.03	66980.45	12502.67	175.57	8424.45
2003	78267.07	65684.50	12266.34	175.07	9573.04
Average	81,978	69,666	12,193	175	8,748

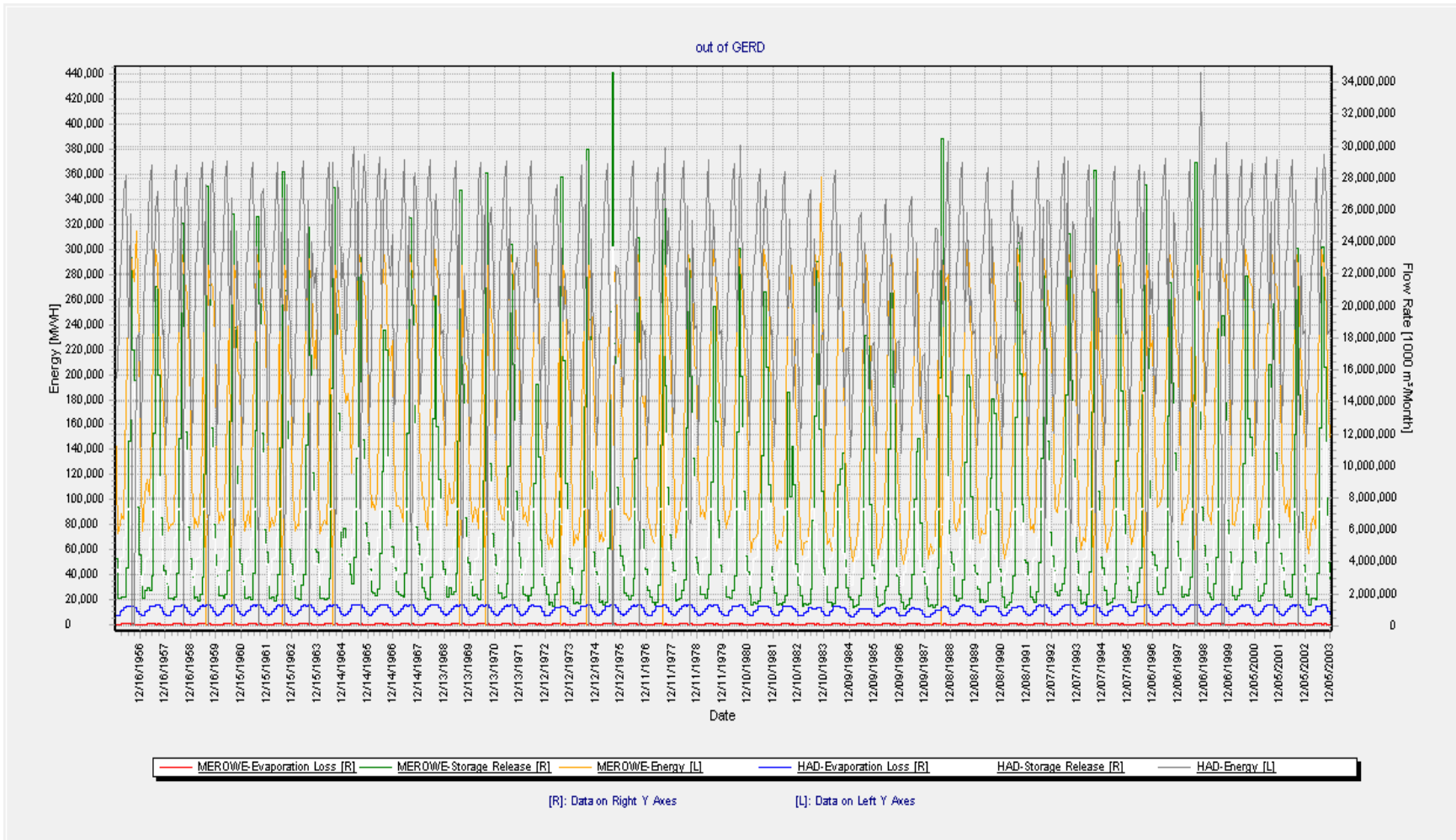
Appendix 5- MODSIM model simulation results



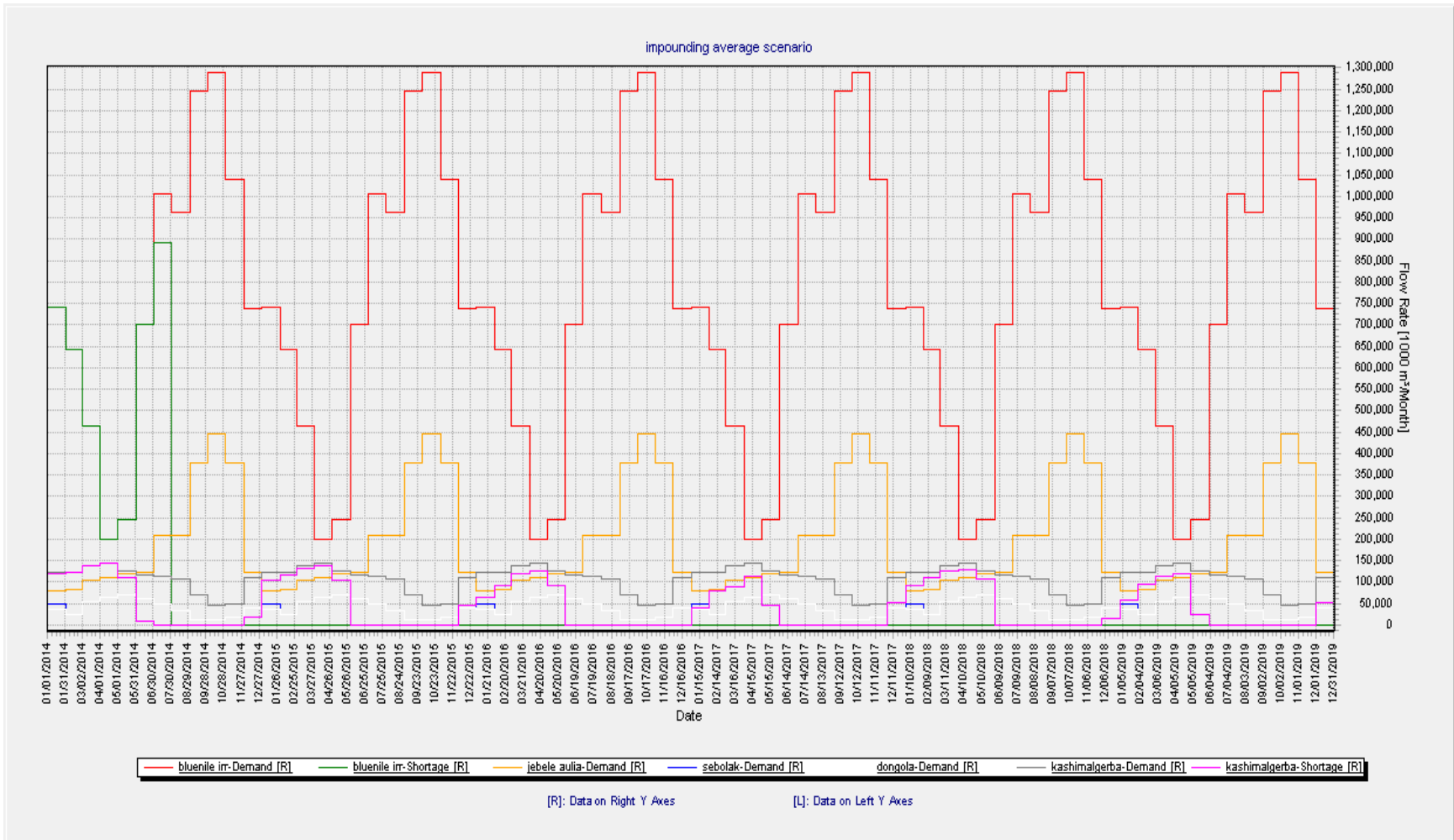
Appendix 5- 1 MODSIM modeling simulation results during average impounding scenario



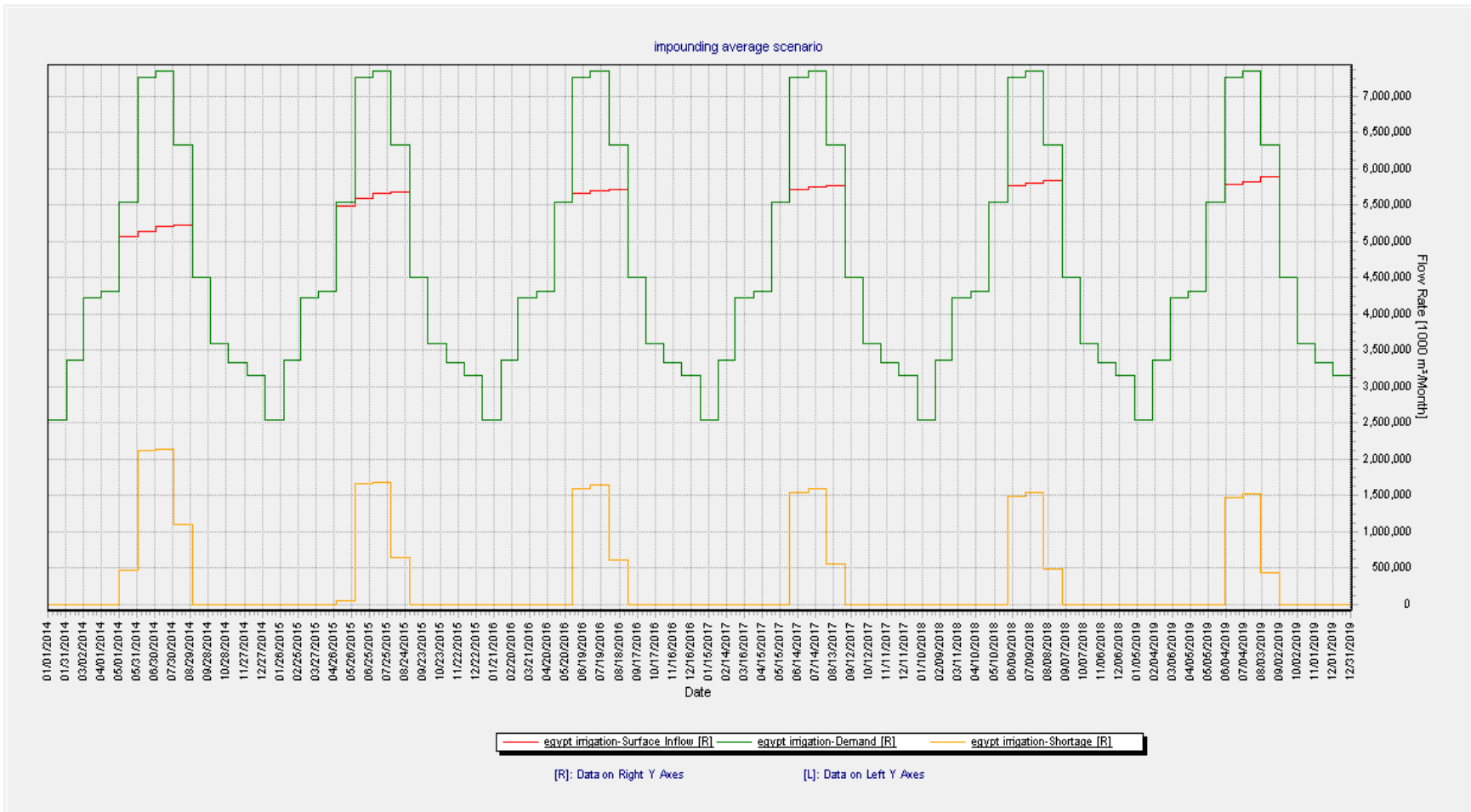
Appendix 5- 2 MODSIM modeling simulation results during dry impounding scenario



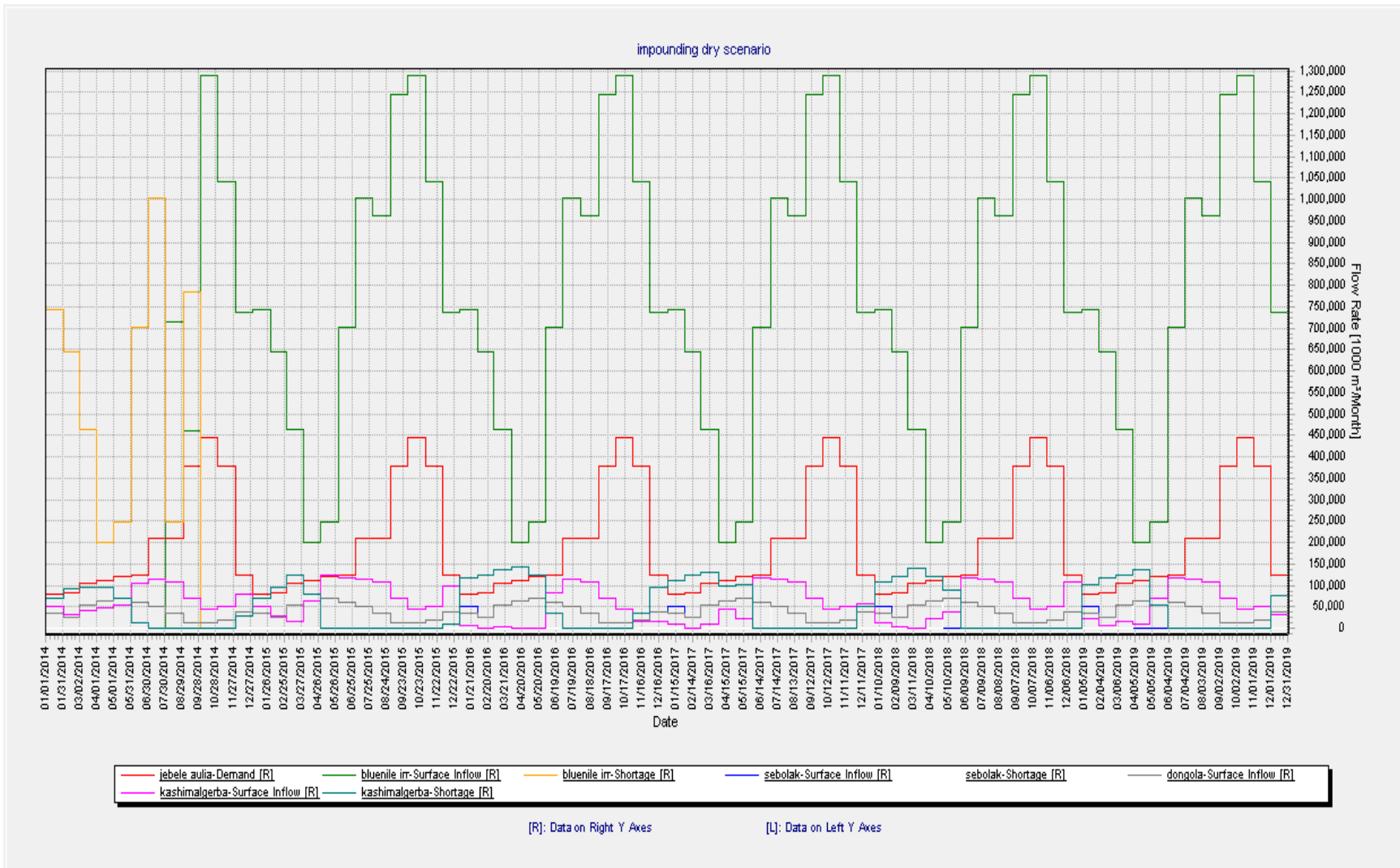
Appendix 5- 3 MODSIM modeling simulation results base line scenario



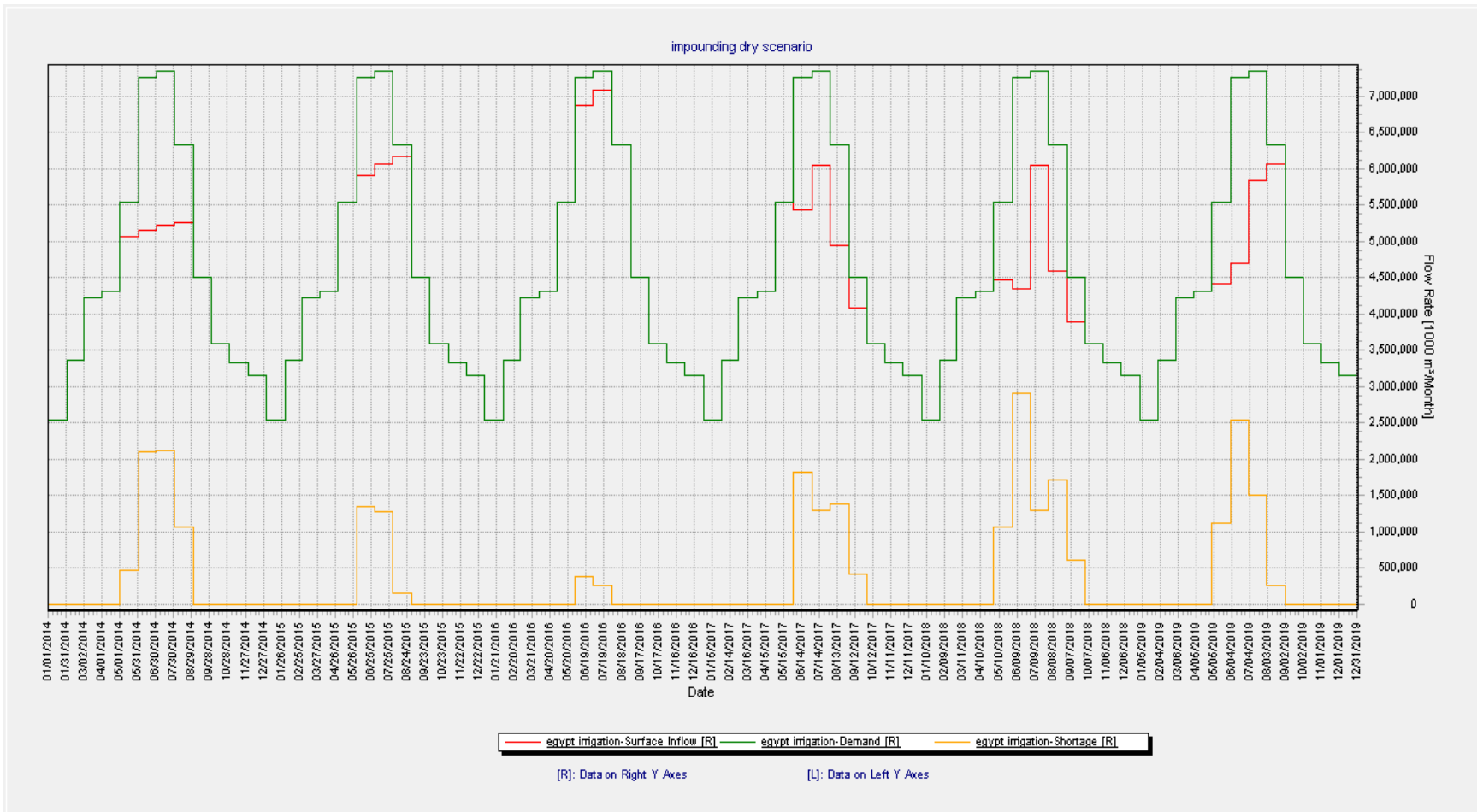
Appendix 5- 4 Sudan irrigation water use during normal impounding scenario



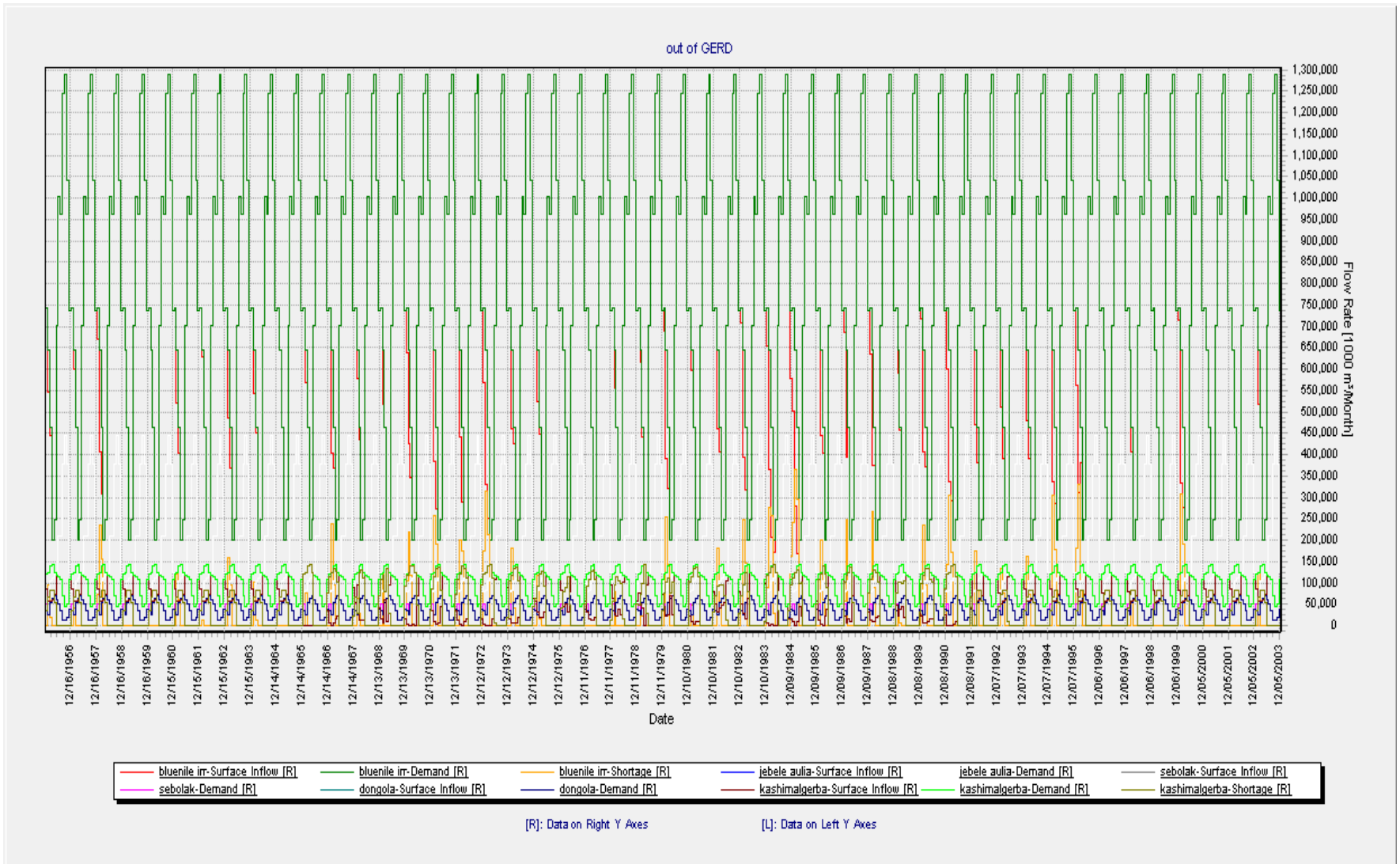
Appendix 5- 5 Egyptian irrigation water use during impounding -normal scenario



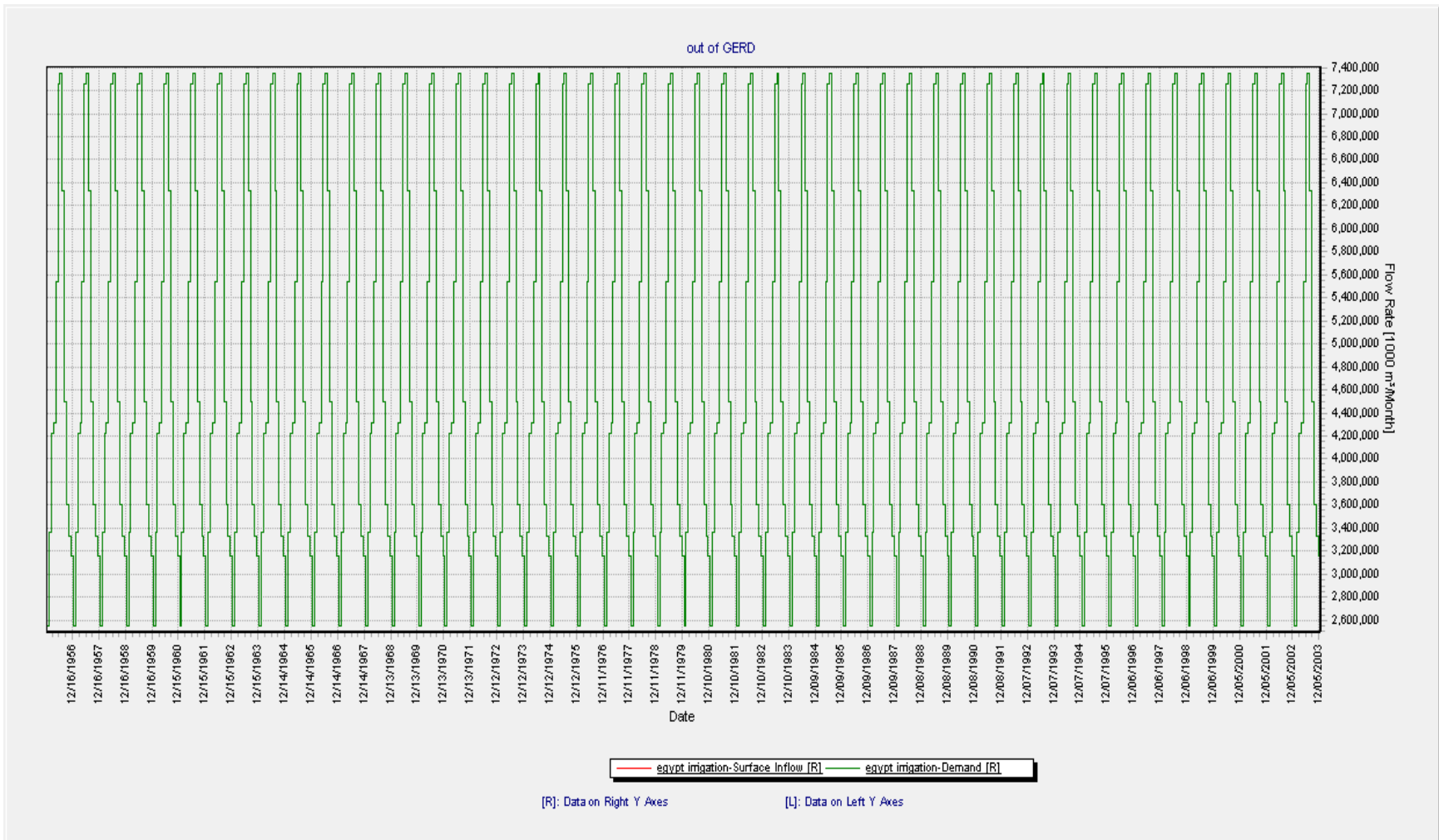
Appendix 5- 6 Sudan irrigation water use during impounding -dry scenario



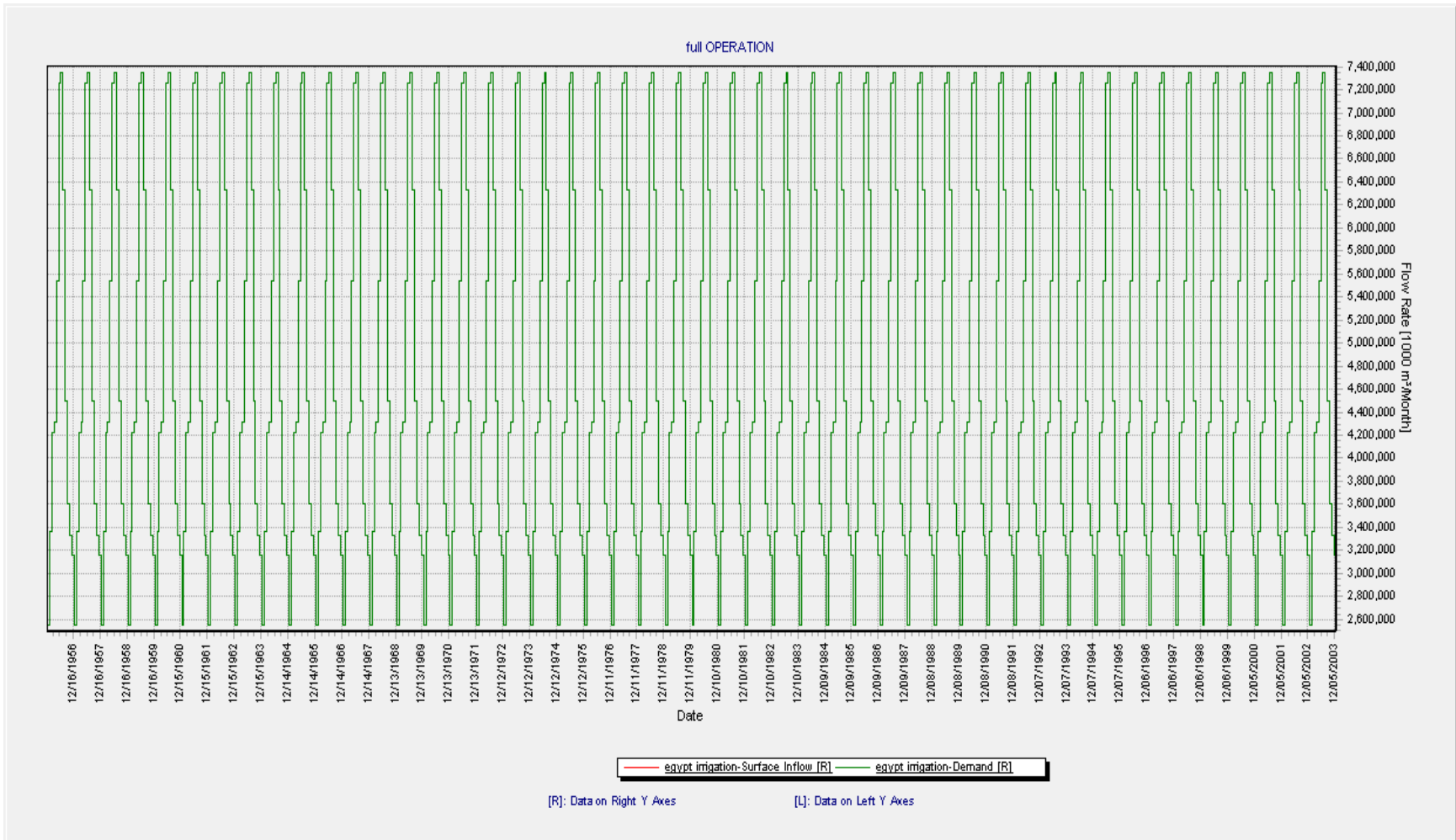
Appendix 5- 7 Egyptian irrigation water use during impounding –dry scenario



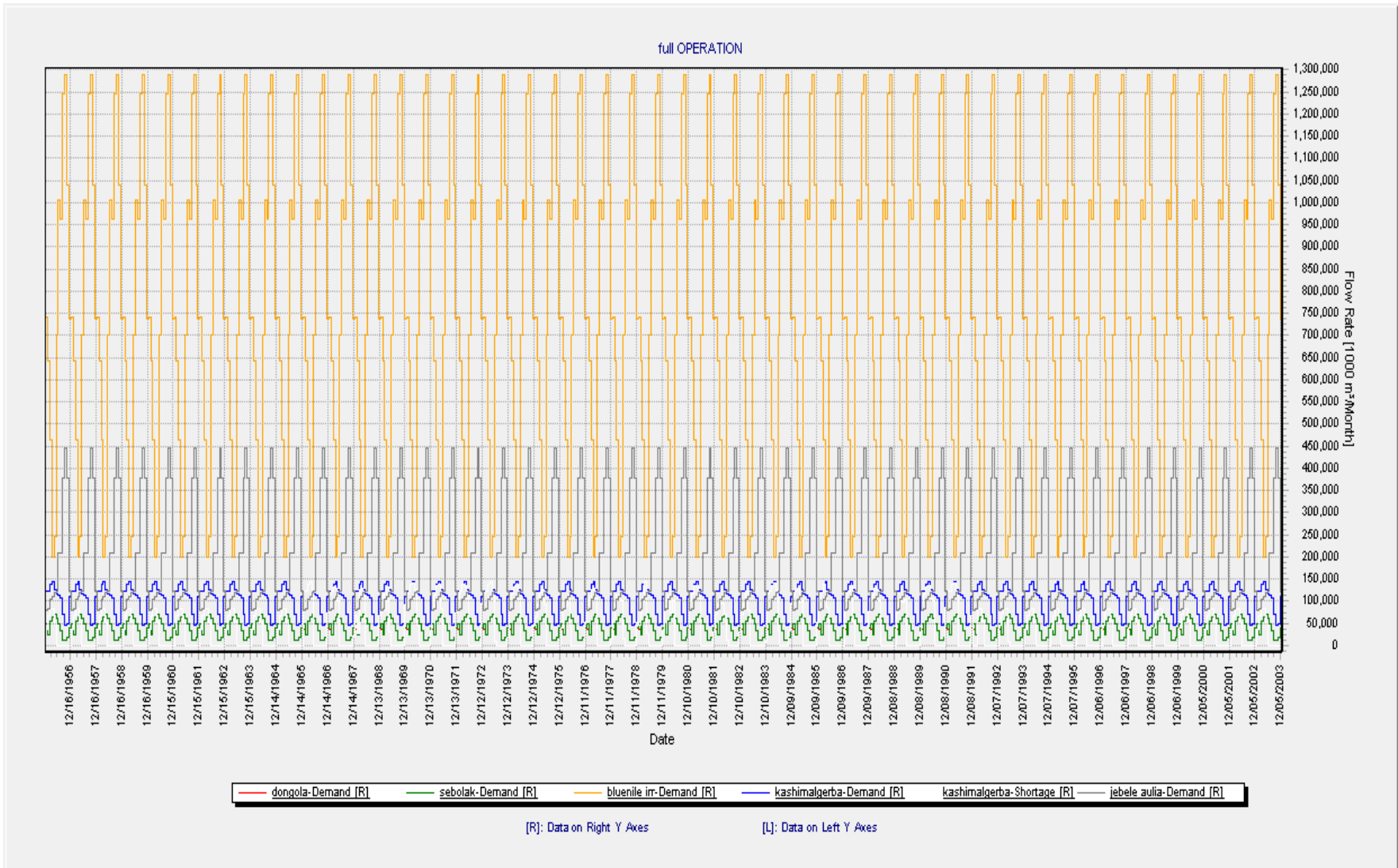
Appendix 5- 8 Sudan irrigation water use during baseline scenario



Appendix 5- 9 Egyptian irrigation water use during baseline scenario



Appendix 5- 10 Egyptian irrigation water use during long term future scenario



Appendix 5- 11 Sudan irrigation water use during long term future scenario

