مجلة المجلس العربى للمياه
Arab Water Council Journal

المجلس العربى للمياه
Arab Water Council

The Official Journal
of the Arab Water Council

Indexed in
EBSCO
INFORMATION SERVICES

Volume 10, No.2, December 2019

ISSN 1996 - 5699

المجلس العربي للمياه
Arab Water Council

مجلة المجلس العربي للمياه
Arab Water Council Journal

AL- MAA

The Official Journal
of the Arab Water Council

Indexed in
EBSCO
INFORMATION SERVICES

Volume 10, No.2, December 2019 ISSN 1996 - 5699

Arab Water Council Journal
The Official Journal of the Arab Water Council
Scientific and Refereed Semi-annual Journal

Publisher

Arab Water Council
Cairo, Egypt
www.arabwatercouncil.org

Research papers as well as other correspondence concerning this journal should be addressed to:

Dr. Aly N. EL-Bahrawy
Editor-in-Chief
Arab Water Council Journal
Tel: + 20 2 24023276
Fax : + 20 2 22600683
Cell: + 20 122 7340569
Email: alyelbahrawy@arabwatercouncil.org

Copyrights: All copyrights are reserved to the Arab Water Council. No part of this publication may be reproduced or transmitted in any form or by any means without prior written permission from the AWC. Photocopying copyright is permitted only to individuals for the purpose of private research and higher education.

Arab Water Council Journal

Editorial Board

Under the Supervision of:

Prof. Dr. Mahmoud ABU-ZEID
President, Arab Water Council
& Former Minister of Water Resources and Irrigation, Egypt
E-mail: president@arabwatercouncil.org

Editorial Board

Dr. Aly N. EL-BAHRAWY
Editor-in-Chief
Arab Water Council Journal
Cell: +20 122 7340569
E-mail: alyelbahrawy@arabwatercouncil.org
journal@arabwatercouncil.org

Prof. Walid A. ABDERRAHMAN
Editorial Board Advisor
Vice President, AWC
E-mail: walid@acwaholding.com

Dr. Hussein EL-ATFY
Editorial Board Advisor
Secretary General
Arab Water Council
E-mail: hielatfy@arabwatercouncil.org

Prof. Safwat ABDEL-DAYEM
Editorial Board Advisor
Arab Water Council Advisor
E-mail: safwat@arabwatercouncil.org

Prof. Shaden ABDEL-GAWAD
Former President, NWRC-Egypt
E-mail: shaden.gawad@gmail.com

Prof. Khaled ABU-ZEID
Regional Director for Technical Programs,
Arab Water Council
E-mail: kabuzeid@arabwatercouncil.org

Prof. Abdin SALIH
Professor - Faculty of Engineering
University of Khartoum- Sudan
E-mail: abdeensalih@gmail.com

Dr. Theib Y. OWEIS
Director of Water and Drought Program
International Center for Agricultural Research in the Dry Areas (ICARDA) -Syria
E-mail: t.oweis@cgiar.org

Eng. Saif Mohamed ALSHARA
Executive Director for Water Resources and Nature Preservation
Ministry of Environment and Water, UAE
E-mail: smalshara@moew.gov.ae

Mr. Nasser NASRALLAH
President
Association of the Friends of Ibrahim ABDEL AAL, Lebanon
E-mail: Abdelal@cyberia.net.lb

Executive Editor

Dr. Mary K. HALIM
Technical Consultant
Documentation/Publication
Arab Water Council
E-mail: maryhalim@arabwatercouncil.org

Editorial Assistant

Ms. Reham H. HASSAN
Executive Secretary,
General Secretariat (AWC)
E-mail: rehamh@arabwatercouncil.org

Cover Design

Ms. Mona F. RAMADAN
E-mail: journal@arabwatercouncil.org

Arab Water Council Journal

Aims and Scope

The Arab Water Council Journal is a scientific refereed Journal published twice a year by the Arab Water Council. The mission of the Journal is to contribute to solving Arab and Regional water issue by publishing scientific papers in the areas of integrated water resources management, water policies, trans-boundary water issues, water conflicts and diplomacy. In addition, the Journal addresses traditional water issues in different sectors, namely: urban, industrial, agricultural and transportation. The specific objectives of the Journal are:

1. Provide a forum for debate and create a dialogue among water researchers and professionals to exchange knowledge and experience.
2. Enhance conducting research in integrated water resources management and its comprehensive policy framework.
3. Contribute to the advancement of scientific research in water management within the context of sustainable development.

The Journal will publish research papers, review articles, technical notes, case studies and progress reports in all management and policy aspects of water resources in the following areas:

- Integrated Water Resources Management
- Planning the use of natural resources and river basin management
- National policies in water resources management and development
- Water governance and water institutions
- Water laws and legislative water resources policies
- Economic and social aspects of water resources management and water services
- Water security and dealing with scarcity
- Management of non-conventional water resources
- Technical, economic and management aspects of water desalination
- Management and economical analysis of large water resources and their uses
- Climate changes and their impacts on water resources and their uses
- The use of modern and robust research tools in water management
- Crises management in cases of drought and floods
- Hydro-politics and trans-boundary water issues and conflict resolution
- Policies toward sustainable eco-system and restoration management and mechanisms
- Successful and unique case studies and lessons learned in IWRM

The published articles reflect the opinions of the authors and do not necessarily reflect the opinion of the editorial board, the policy of the Journal or the policy of the Arab Water Council.

Guide to Authors for Paper Submission

The Arab Water Council Journal publishes research papers that exhibit originality and scientific approach. Papers in both Arabic and English languages are encouraged, provided they address the water problems of the Arab region. Original research and policy papers, synthesis papers, review papers, discussions, or technical notes are accepted for publication.

Following are the general guidelines for the process of publication:

1. The manuscript should be submitted as soft copy addressed to the Editor-in-Chief via e-mail as an attachment (journal@arabwatercouncil.org).

2. The authors' names (first and last) with their affiliations should be written below the title, while the corresponding author is to be identified including his e-mail and full contact details.

3. Authors of papers written in Arabic should submit an additional Abstract in English language following the Arabic abstract. The abstract should present a concise statement of the scope, principal findings, and conclusions of the paper. Each abstract should be followed by keywords and should not contain more than 200 words.

4. Manuscript format:
   - Manuscripts should normally not exceed 6000 words; shorter is better.
   - Page size: B5 (17.6 ×25 cm) * Margins: 2.5 cm (from all sides)
   - Spaces between lines: 1.15
   - Spaces between paragraphs: 6 points after paragraphs and titles
   - Font & Size (in body of text): Times New Roman, 10-point type.
   - Titles:
     * Manuscript title: Times 14 Bold (upper case)
     * Main headings (level 1): Times 12 Bold (upper case).
     * Sub-headings (level 2): Times 11, Bold & italics (sentence case).
   - In case of Arabic papers:
     *Font & Size : Arial 12 * Manuscript Title: Arial 16 Bold
     *Main headings (level 1):Arial 14 Bold * Sub-headings (level 2): Arial 13, italics, bold
   - Numbering system of main headings and sub-headings: eg. 1, 1.1, 1.1.1, etc.
   - Use header in all pages including: Journal title, Volume No., Issue No., date (month & year). Example: *Arab Water Council Journal, Vol. 2, No. 1, July 2011*.
   - All measurements should be in metric units.
   - Scientific abbreviations may be used provided they be explained when first appear in the text.
   - Page numbers: bottom center (will be re-adjusted by journal editor).

Manuscript should be saved using Microsoft Word 2007 (.docx).

5. Refer to tables as (Table 1, etc.), numbered sequentially. All illustrations including maps, diagrams, charts and photographs must be submitted as sequentially numbered figures (Figure 1, etc.) in the order referred to in the text, and they should have brief caption details and source details where appropriate. The figures should be supplied in electronic format as JPG, TIF or GIF files. Pictorial illustrations must be at a resolution of no less than 300 dpi/ppi, and line diagrams at a resolution of no less than 1200 dpi. All figures and tables must be embedded within the text and should fit within the margin settings.

6. References should be cited in the text by giving the last name of the author(s) followed by the year of publication in parentheses, e.g. Smith & Jones (1990); (Smith, 1992a, 1992b). For three or more authors, use the first author followed by *et al.*

7. The full references should include all authors' names and initials, year of publication, title of article or book, the full title of the journal, volume and page numbers and, for books and other documents, the publisher's name and place of publication, e.g.

Hobbs, P.; Oelofse, S.H.H. and Rascher, J. (2008). Management of environmental impacts from coal mining in the Upper Olifants river catchment as a function of age and scale, International Journal of Water Resources Development, 24(3), pp. 417-431.

Books, D. (2008). Human rights to water in North Africa and the Middle East: What is new and what is not, what is important and what is not. In : A.K. Biswas; E. Rached and C. Tortajada (Eds). Water as a Human Right for the Middle East and North Africa, pp. 19-34 (London: Routledge).

8. By submission of a manuscript, an author certifies that the work is original and is not being considered simultaneously by another publisher. The Editorial Board shall be responsible for informing the authors of any measure taken concerning their manuscript such as receiving, accepting or rejection. The manuscript will be sent to a minimum of two independent reviewers, but may be sent back to the authors for revision. Submission of the revised manuscript should be made within one month. The papers accepted for publication shall be published according to the final date of acceptance.

9. The Arab Water Council is the copyright holder and is the only authorized agent to give permissions to reproduce the manuscript.

10. The authors will receive one copy of the journal issue in which the manuscript appears.

The Official Journal of the Arab Water Council

Journal Subscription Form

Subscription Fees

	One year	3 years
1. Subscription fees for AWC members	15 US$	40 US$
2. Subscription fees for individuals	30 US$	75 US$
3. Subscription fees for organizations and universities	100 US$	250 US$

Subscription Request to be addressed to:

Attention of the Arab Water Council Journal
Please accept my subscription to the Journal for a period of ( ) years
starting from / /
Name of subscriber: ……..
Address: ……..
……..
e-mail: ……..

Form of payment:

1- Payment by Bank transfer
CIB BANK
Commercial International Bank (Egypt) S.A.E.
12 El-Saleh Ayuob St., Zamalek – Cairo, Egypt
Zamalek Branch
Swift Code: CIBEEGCX007
Arab Water Council المجلس العربي للمياه
US$: 100009192713
L.E.: 100006729384
Euro: 100011207768

2- Cash Payment
At the Arab Water Council Headquaters
Membership Officer
9 AlMokhayam AlDa'em Street, AlHay AlSades
Nasr City, 11471, Cairo, Egypt

3- Payment by Check
to the Arab Water Council

Table of Contents

- Potential Hydrological Impacts of the Grand Ethiopian Renaissance Dam on Egypt & Sudan (*Khaled M. AbuZeid*)……..……..……..……1

- Using Remote Sensing in Land Reclamation Monitoring in Egypt (*Heba M. Salman, Moamen El-Sharkawy & Aly N. El-Bahrawy)*.....…40

Technical Articles

- How Can the Arab World Leapfrog Uncharted Waters for Sustainable Development? (*Ayat Soliman & Hassan T. Aboelnga)*.....56

Potential Hydrological Impacts of the Grand Ethiopian Renaissance Dam on Egypt and Sudan

Khaled M. AbuZeid, PhD, PMP, PE
Regional Water Resources Director
Centre for Environment and Development for the Arab Region (CEDARE)
kabuzeid@cedare.int

Abstract

The Blue Nile originates in Ethiopia and flows downstream through Sudan where it joins the White Nile to form the Main Nile which flows downstream into Egypt, the most downstream country on the Nile River. The Blue Nile represents the largest tributary to the Main Nile providing an average annual flow of about 50 Billion Cubic Meters (BCM) which is about 60% of the natural average flow of the Main Nile at Aswan in Egypt. Egypt depends on the Nile River waters as its main source of renewable water resources utilizing an annual amount of 55.5 BCM as per the 1959 agreement which entitles Sudan to 18.5 BCM per year, also representing a high dependency of Sudan on the Nile waters. Ethiopia embarked on the construction of the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile in 2011 with the announced objective of hydropower generation. The GERD's reservoir maximum storage capacity is 74 Billion Cubic Meter (BCM) and is announced to start filling in 2020 and to be in full operation by 2023. The transboundary impacts of the GERD filling and operation on the flows of the Blue Nile downstream need careful attention.

This paper presents an assessment of the transboundary hydrological impacts of the GERD filling and operation on the downstream flows to Sudan and Egypt. The assessment highlights the implications of the GERD, especially during years of drought, using 105 historical years of Blue Nile flows. Five different initial water levels of the High Aswan Dam (HAD) reservoir in Egypt at the start of first filling of the GERD upstream the Blue Nile were simulated, with ten different scenarios for annual operation. Three different scenarios of first 10-year average flows of Blue Nile were simulated. The combinations of these scenarios represent a large set of scenarios, some of which are presented in this paper.

The Nile River Basin and the Blue Nile Basin

The Nile basin in Ethiopia receives about 450 BCM of rain per year out of a total of 970 BCM falling on Ethiopian lands. Ethiopia has several aquifers and river basins other than the Blue Nile, Sobat and Atbara basins associated with the Nile basin in Ethiopia. Ethiopia with its largest livestock production in Africa depends on rainfed natural pasture lands for feeding. The geographical climate variability and the distribution of rainfall on the Nile basin countries necessitated Egypt's and Northern Sudan's dependence on the river's water and Ethiopia's reliance on direct rainfall, which contributes to vast areas of forests, pasture and rainfed

agriculture in Ethiopia, as well as recharging a vast reservoir of renewable groundwater. It is therefore normal that the upstream countries such as Ethiopia rely on "rainwater" in the Nile Basin whereas the downstream countries such as Egypt and Sudan rely on "running water" in the Nile River itself. Egypt and large areas of Sudan are considered arid and hyper arid areas where there is practically no rainfall. Egypt and Sudan do not represent a large part of the water uses of the Nile Basin waters. Egypt's & Sudan's shares represent about 4.6% of the total rainfall which is about 1660 BCM per year on average, falling on the Nile basin in the 11 Nile basin countries. The rainfall in the Nile countries, including other basins, reaches about 7000 BCM annually on average. Due to temporal climate variability these rainfall amounts could be less or more in different years. Figure 1 shows the distribution of rainfall on the Nile Basin countries, which shows the wide range of spatial geographical climate variability.

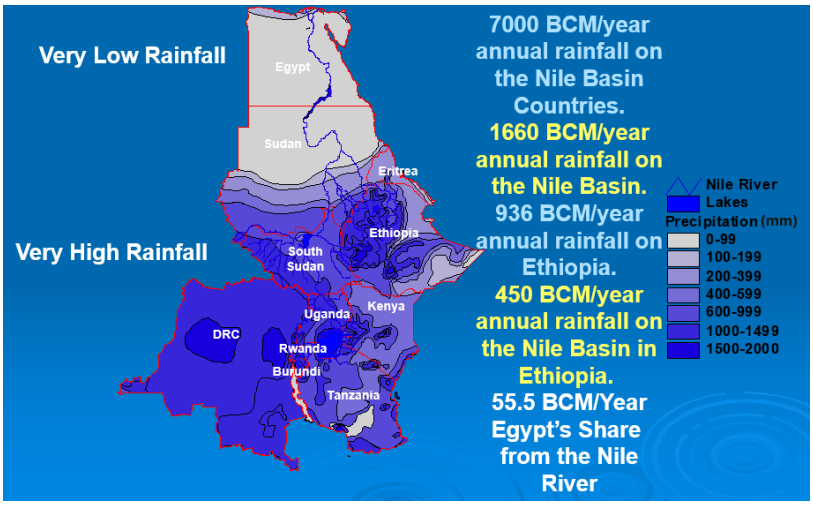

Figure 1: Rainfall Distribution on the Nile Basin Countries [K. AbuZeid (2012)]

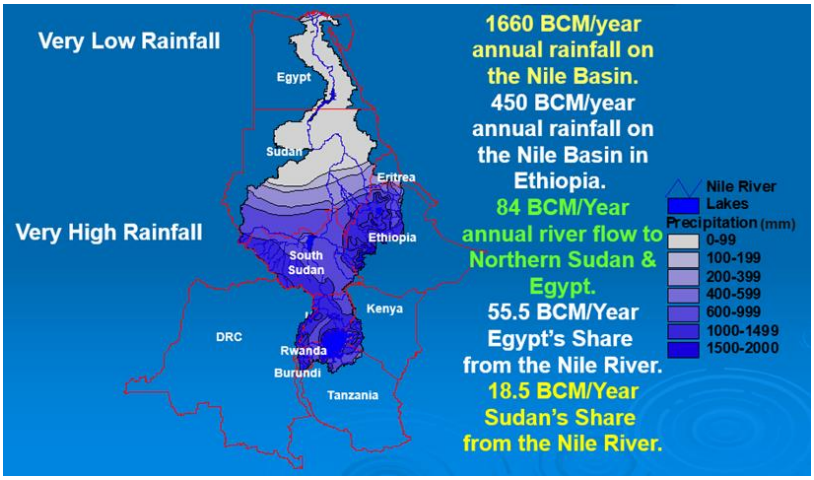

Figure 2: Rainfall Distribution on the Countries within the Nile Basin [K. AbuZeid (2012)]

According to the 1959 agreement, Sudan's annual share from the Nile is 18.5 BCM. Egypt's annual share is 55.5 BCM (Figure *2*), which is not only governed by the 1959 agreement, but is also confirmed by historical and increasing needs and actual uses for decades. This share is not enough for Egypt's water needs. Egypt's import of agricultural food products in 2015, according to K. AbuZeid (2018), reached about 50 BCM of the virtual water needed to grow these products. Egypt is the only country in the Nile Basin countries that has been obliged to reuse wastewater and agricultural drainage to fulfill its water demand. It has also begun for decades to desalinate seawater to fill the water gap on the coasts of the Red Sea and recently in the cities on the Mediterranean Sea. Although Satellite images confirm Ethiopia's use of the Blue Nile water in agriculture, industry and urban developments, no data is published showing the exact abstractions or water uses in the Blue Nile Basin in Ethiopia. However, Ethiopia's agriculture uses are more dependent on rainfed agriculture. The Blue Nile is the main tributary of the Nile River with the largest flow among all major tributaries discharging about 50 BCM/year on average. The effect of annual climate variability on the Blue Nile flows during the period from year 1911 to 2015, shows a range from 20.69 BCM/y in year 1913 to 69.85 BCM/y in year 1929. The Blue Nile originates in Ethiopia, and flows downstream to Khartoum in Sudan where it joins the main Nile which then flows into Egypt.

The "GERD" and the "Agreement on the Declaration of Principles"

Ethiopia launched the construction of the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile in Ethiopia in April 2011 and the construction volume reached about 70% in 2019. The pictures in Figure 3 show the progress of construction in the GERD and the auxiliary Saddle Dam as of 2019.

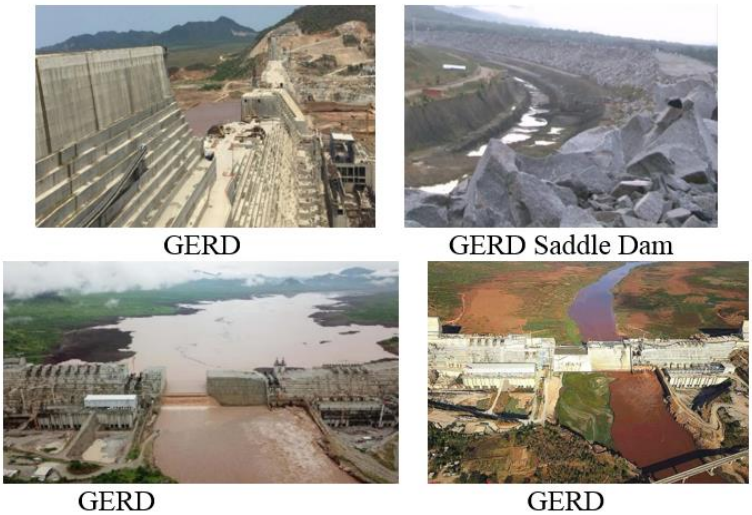

Figure 3: Progress of Construction in the GERD and the Auxiliary Saddle Dam as of 2019

GERD has raised a lot of controversy due to its potential impacts on the downstream countries, Egypt and Sudan. In an attempt to assess the impact of the GERD on Egypt and Sudan during the period of filling and during the period of operation, the Center for Environment and Development of the Arab Region and Europe (CEDARE) conducted a comprehensive study on the potential impacts of the GERD on Egypt and Sudan [K. AbuZeid (2017a)]. Some of the results of this study are presented here.

The "Agreement on the Declaration of Principles on the GERD", signed by the leaders of the three countries (Egypt, Ethiopia and Sudan) in March 2015, stipulated that the three countries will agree on "the guidelines and rules of the first filling and the annual operation and will set up an appropriate coordination mechanism among them to sustain cooperation and coordination of the operation of GERD with downstream reservoirs". It was therefore important to study the expected scenarios of the potential impacts of the GERD on the downstream countries of Sudan and Egypt, so that countries would make their decisions on filling and operating rules based on the results of these studies. A consortium of 2 consulting firms was jointly hired by the 3 countries to conduct the formal impact assessment studies. However, the progress of the studies has been halted due to Ethiopia's rejection of the inception report.

The images in Figure 4 show the High Aswan Dam (HAD) that lies in the downstream of the GERD in Egypt which is the control structure that regulates the releases of flows for Egypt's Uses as per the 1959 agreement with Sudan which allocates 55.5 BCM/year for Egypt and 18.5 BCM/year for Sudan.

Figure 4: High Aswan Dam (HAD) (Egypt)

GERD Impact Assessment: Methodology, Scenarios & Assumptions

The study on the impacts of the first filling and the operation of the GERD was based on simulating several possible scenarios which reached more than 100 scenarios (K. AbuZeid, 2017a). The amount of the first seepage losses, annual seepage and annual evaporation from the GERD reservoir were estimated based on the volume of storage and the water surface area of the GERD Reservoir. The study presents scenarios for the first filling volume of up to 15 BCM, 18.4 BCM, 25 BCM, 39.3 BCM, and 49.3 BCM over a period of 6 years, 10 years and some cases over a period of 3, 4 and 5 years. K. AbuZeid (2016, 2017a and 2018a) showed that the filling period is not that critical for scenarios that start with 10 years of moderate (45 BCM/y) to average (50 BCM/y) 10-year Average Blue Nile flows while the HAD levels

are above 175 m at the beginning of the filling period. This study is based on simulating the historical series (1911-2015) of the Blue Nile flows on which GERD is being built in the Ethiopian lands. Different scenarios of water levels in the High Aswan Dam (HAD) reservoir of 150 meters (m), 160, 165, 170 and 175 m above mean sea level (amsl) were considered as the HAD levels at the beginning of the first filling of the GERD reservoir in the Upper Blue Nile. Different combinations of these variables created the scenarios that were studied and simulated into the future assuming the GERD was in place. The impact of GERD on the flows of the Blue Nile downstream and the water levels and storage volumes of the HAD reservoir, while trying to meet Egypt and Sudan's shares of the Nile water were compared to the Baseline scenario (without GERD). The number of years of water deficit for Egypt and Sudan, and the volume of this deficit were assessed for every scenario. Since there is no agreement yet on the operating rules of the GERD, operating rules' assumptions and scenarios of operation had to be made. The annual operating rules (after the filling period) were based on lowering the reservoir levels of GERD by the end of each hydrological year back to the first filling volume, under the different scenarios of 15 BCM, 18.4 BCM, 25 BCM, 28.9 BCM, 39.3 BCM, and 49.3 BCM of first filling volume assuming these are going to be the "Minimum Operating levels". Different alternatives of maximum storage were also simulated putting a cap on the maximum GERD storage of 18.4 BCM, 39.3 BCM, 49.3 BCM, 60.6 BCM, 70.88 BCM, and 74 BCM.

The "first filling" is considered to be filling up the dead storage in addition to a safety height of about 20 m above the level of the main turbines, until 590 m (amsl), which is equivalent to a total storage around 15 BCM. Some scenarios assume the "first filling" was going to be up to the "Minimum Operating Level" where different alternatives of GERD "Minimum Operating Levels" were simulated. The relationship between the water level in the GERD reservoir, the water surface area, and the storage volume in the GERD reservoir follows the chart shown below in Figure 5.

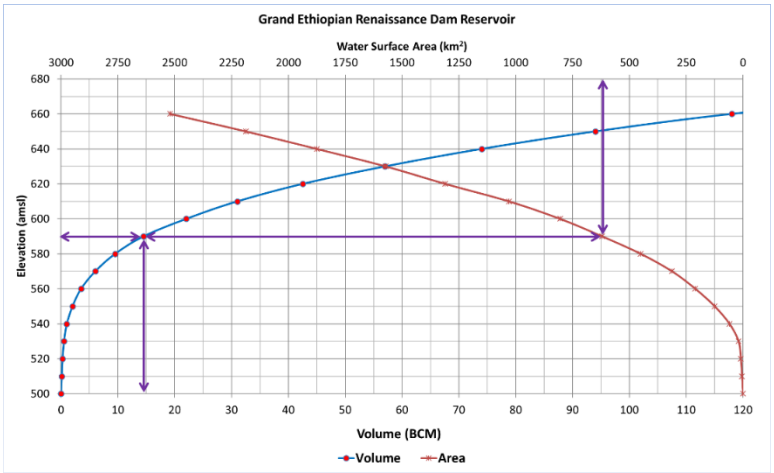

Figure 5: GERD Reservoir Water Elevation, Surface Area & Storage Volume

The "first seepage" and "annual seepage" from the GERD reservoir were assumed as per the "average scenario" in the charts below shown in Figure 6 & Figure 7.

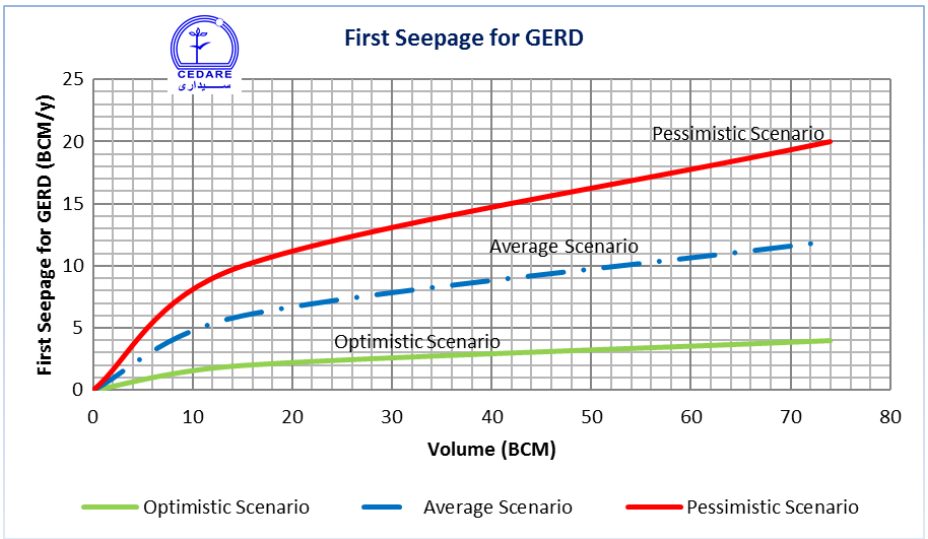

Figure 6: The "First Seepage" Scenarios from GERD Related to the "Storage Volume"

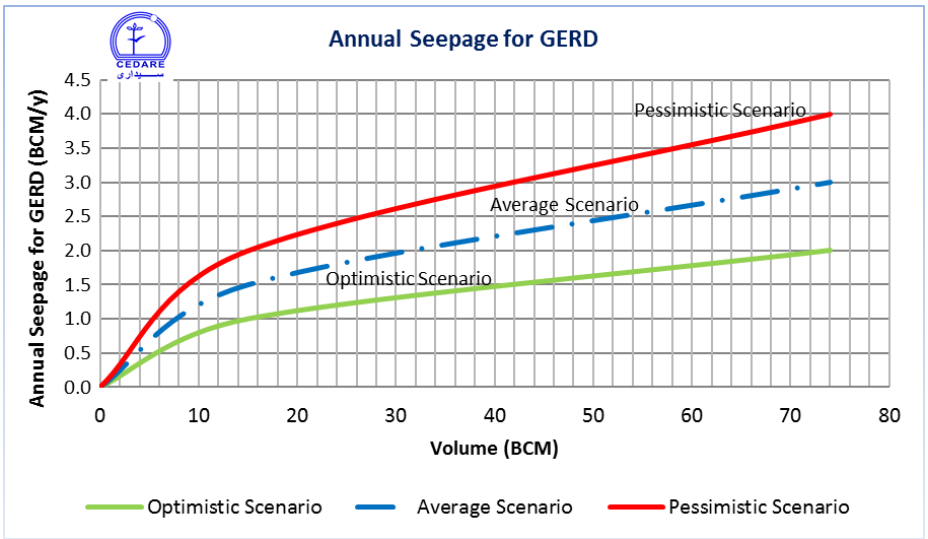

Figure 7: The "Annual Seepage" Scenarios from GERD Related to the "Storage Volume"

According to Wale (2008), the evaporation rate from Lake Tana in Ethiopia, whose surface water level is at 1786 m (amsl), is about 4.63 mm/day. According to Bashar & Mustafa (2009), the evaporation rate from the Roseires Dam reservoir in Sudan, whose water level is at 480 m (amsl), has an average evaporation rate of about 6.62 mm/day. As the GERD highest water level is at about 640 m (amsl), by interpolation the evaporation rate may be estimated at the GERD reservoir to be 6.38 mm/day. This estimated evaporation rate is reflected by the

"interpolation scenario" for GERD "annual evaporation" as shown in the chart in Figure 8 after converting the daily rate to an annual rate for a reservoir surface area of about 1800 km^2. The average scenario shown in the chart was the one considered in the assessment.

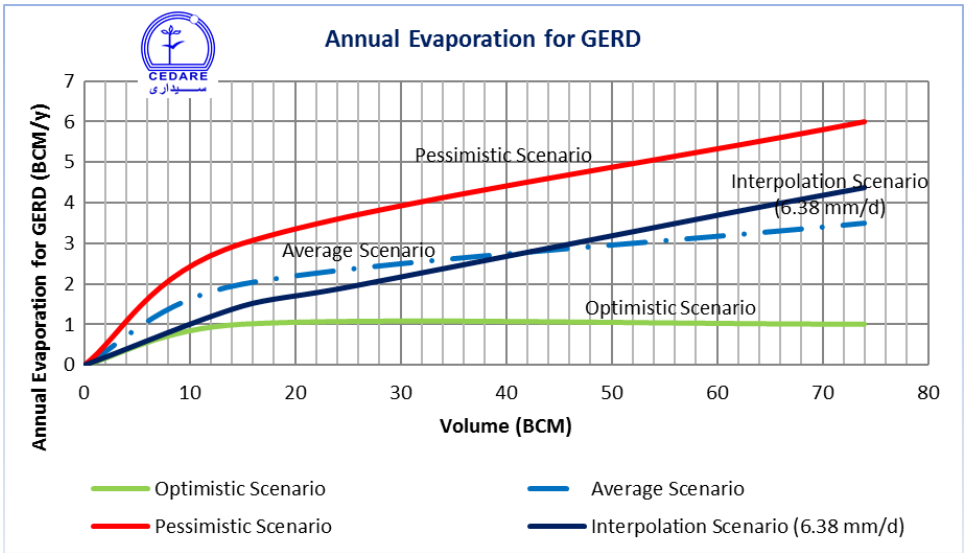

Figure 8: GERD "Annual Evaporation" Scenarios Related to "Storage Volume"

The relationship between the water level in the HAD reservoir, the water surface area and the storage volume, is presented in the chart shown in Figure 9.

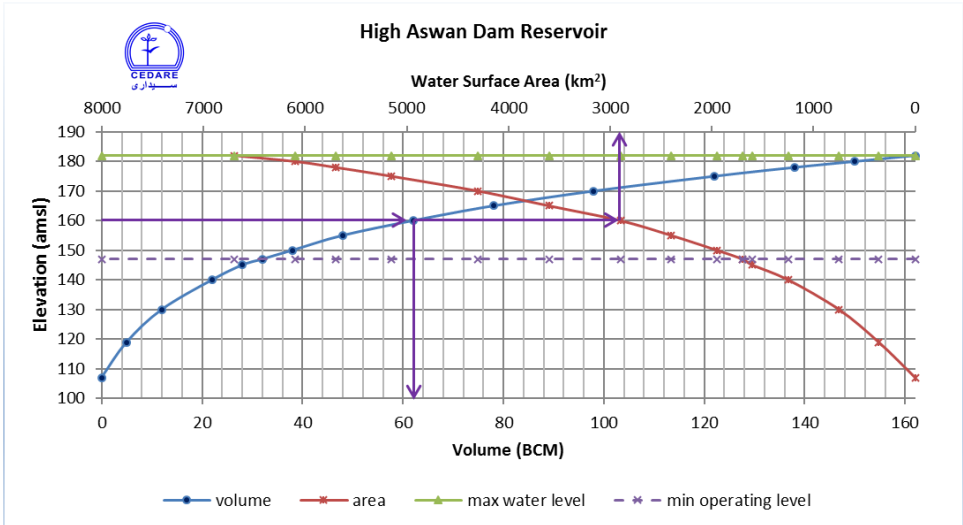

Figure 9: HAD Reservoir "Water Elevation", "Surface Area" & "Volume"

According to Abou El-Magd & Ali (2012), the rate of evaporation from the HAD reservoir is about 4.45 mm/day, about 11.1 BCM per year at the maximum water level and surface area of

the reservoir. This is in line with the chart below (Fig.10) for calculating the evaporation and seepage losses from the HAD Reservoir, assuming seepage losses of about 2 BCM/y at maximum water level. The Assumption of evaporation and seepage losses from the HAD reservoir were estimated as per the chart shown in Figure 10.

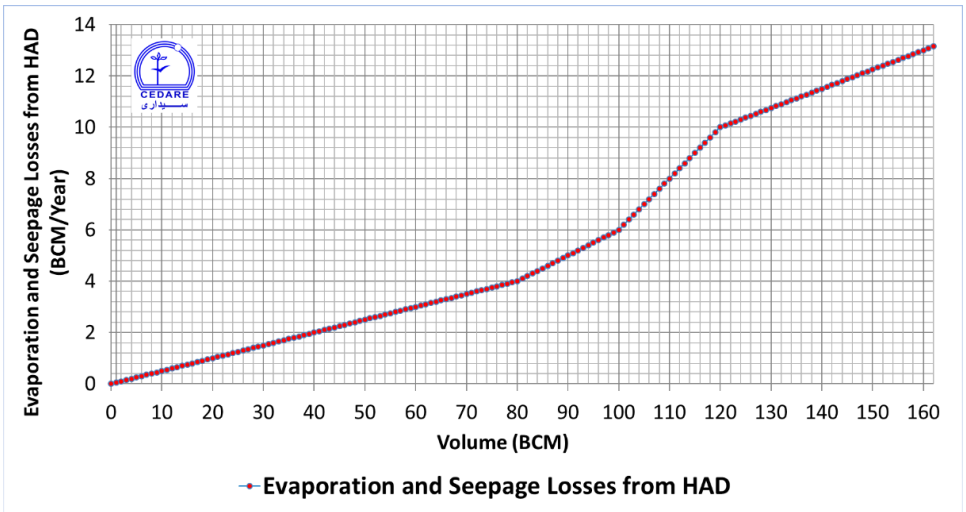

Figure 10: HAD Reservoir "Volume", "Evaporation" & "Seepage Losses"

GERD operating rules are assumed in a way that the Blue Nile flows are stored during the high flow months' period (July-October), which represents about 80% of the total annual discharge, to take advantage of the high levels of hydropower generation from GERD, and to be released throughout the year.

The annual average flows of the main Nile tributaries were considered to be 28.5 BCM/y for the White Nile River at Malakal, 12 BCM/y for the Atbara River, and 4 BCM/y for the Rahad and Dinder Rivers at Khartoum. The total annual losses were considered to be 0.9 BCM/y from the Roseires & Sennar Dam reservoirs, 1 BCM/y from the Atbara, Tekizi, Khashm El-Girba Dams reservoirs, 2.5 BCM/y from Jebel El-Awliaa Dam reservoir, 1.8 BCM/y from Marwi Dam reservoir, and 3.3 BCM/y from the upstream Nile River Reaches until Aswan.

Scenarios of the future Blue Nile series of flows were assumed to begin with 10-year average flows of 38 BCM/year (Lowest Historical 10-year Average), 45 BCM/year (Moderate Historical 10-year Average) and 50 BCM/year (Average Historical 10-year Average). It was assumed that the remaining years in the historical series of the Blue Nile between years (1911 - 2015) will be repeated in the same order for the next 105 years. Scenarios that started with the 10-year average of 50 BCM/y are presented in this paper.

According to the 1959 agreement signed between Egypt and Sudan, which sets Egypt's share from the Nile at 55.5 BCM/y and Sudan's at 18.5 BCM/y, the two countries share any deficit in the Nile waters equally. Scenario simulations were based on fulfilling these shares and determining years of deficit in meeting these shares. Deficit scenarios ranging from 0.5 BCM/y to 5 BCM/y were assumed for each country during deficit years.

It was assumed that the purpose of the GERD is to generate hydropower only, as announced by Ethiopia and implicitly understood by the three countries (Egypt, Sudan and Ethiopia) signing the Declaration of Principles on the GERD in March 2015, and that Ethiopia will commit not to withdraw from the GERD reservoir for any other purposes.

The engineering specifications of GERD in terms of the levels, the elevation and the capacity of the openings and the allowable flow according to the capacity of the turbines follow the cross section and information shown below in Figure 11. It has been decided end of 2019 that 3 out of the 16 originally planned turbines are to be eliminated. The 3 eliminated turbines are shown in red in Figure 11.

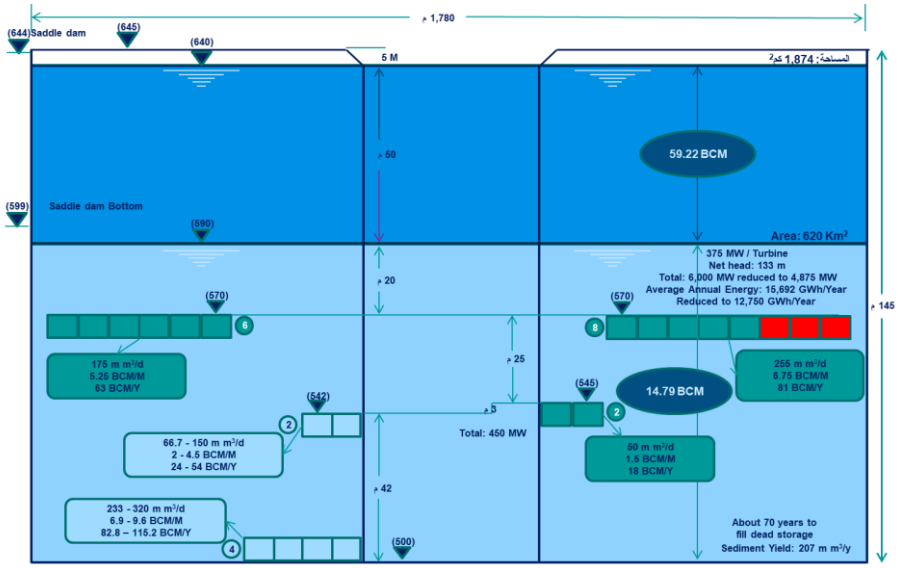

Figure 11: Cross Section and Technical Specifications of GERD Main Features

GERD First Filling Impacts

The following graph in Figure 12 shows a range of scenarios for mainly testing for the first filling, but also included subsequent operation for a 10-year average of Blue Nile flows of about 38 BCM/year at the beginning of the first filling. This range of scenarios shows start of filling when HAD level is at 175 m which is likely to happen. It shows scenarios of first filling of volumes up to 15 BCM, 25 BCM, 39.3 BCM, and 49.3 BCM. Filling periods ranged from 4, 5 to 6 years. Subsequent operational rules for each "first filling scenario" were based on storing the flood flows, which mainly comes during the months of July, August and September, then releasing the stored waters throughout the same hydrological year, until the storage volume returns back to the first filling volume for that scenario. The impact on Egypt and Sudan appears when HAD level goes below the HAD "Dead Storage" level of 31 BCM. The analysis of these particular scenarios shows that the impact of first filling will start to show during the 6th year after the start of the first filling. It shows that the impacts on Egypt's and Sudan's shares extend for about 15 years beyond the filling period. This is mainly associated

with the series of drought years of the Blue Nile and attributed to the accumulated evaporation and seepage losses associated with the GERD reservoir. This becomes apparent when comparing the series of HAD levels scenario curves with GERD in place, to the Baseline Scenario curve without GERD shown in Figure 12. The analysis confirms that for HAD starting level of 175 m, and for the filling volume scenarios ranging from 15 BCM to 49.3 BCM and first filling period of 4 to 6 years, the impact of the GERD's accumulated evaporation and seepage losses will happen during the Blue Nile low flow years. The impact shows at the end of the filling period because the Blue Nile series of low flows coincided with the filling period.

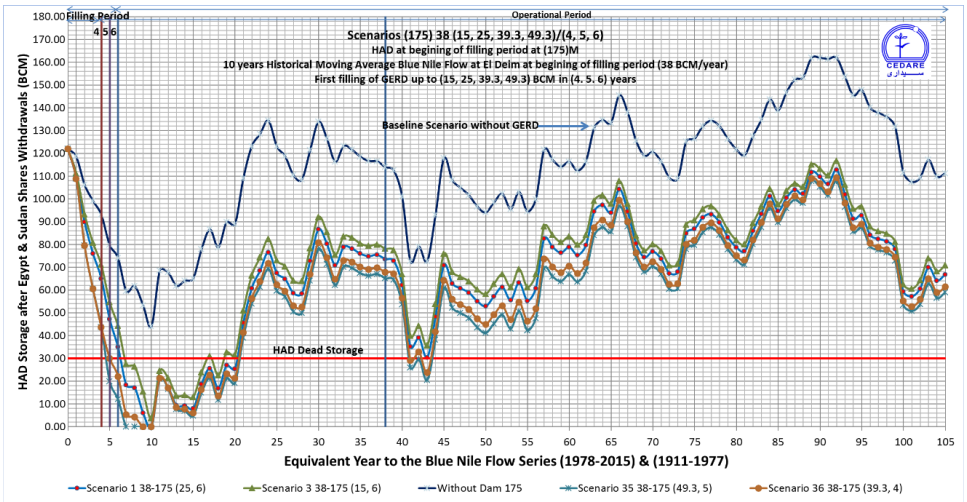

Figure 12: Scenarios (175) 38 (15, 25, 39.3, 49.3) / (4, 5, 6)

The following graph in Figure 13 shows a range of scenarios for mainly testing for the first filling, but also included subsequent operation for a 10-year average of Blue Nile flows of about 45 BCM/year at the beginning of the first filling. This range of scenarios shows start of filling when HAD level is at 175 m which is likely to happen. It shows scenarios of first filling of volumes up to 15 BCM, 25 BCM, 39.3 BCM and 49.3 BCM. Filling periods ranged from 4, 5 to 6 years. Subsequent operational rules for each "first filling scenario" were based on storing the flood flows, which mainly comes during the months of July, August and September, then releasing the stored waters throughout the same hydrological year, until the storage volume returns back to the first filling volume for that scenario. The impact on Egypt and Sudan appears when HAD level goes below the HAD "Dead Storage" level of 31 BCM. The analysis of these particular scenarios shows that the impact of first filling will start to show during the 9th year which is after the end of the filling period by 3 years at least. It shows that the impacts on Egypt's and Sudan's shares extend for about 16 years that are not during the filling period. This is mainly associated with the series of drought years of the Blue Nile and attributed to the accumulated evaporation and seepage losses associated with the GERD reservoir. This becomes apparent when comparing the series of HAD levels scenario curves with GERD in place, to the Baseline Scenario curve without GERD as shown in Figure 13.

The analysis confirms again that for HAD starting level of 175 m, and for the filling volume scenarios ranging from 15 BCM to 49.3 BCM and for the first filling period of 4 to 6 years, the impact of the GERD's accumulated evaporation and seepage losses will happen during the series of Blue Nile low flow years and may not show during the filling period.

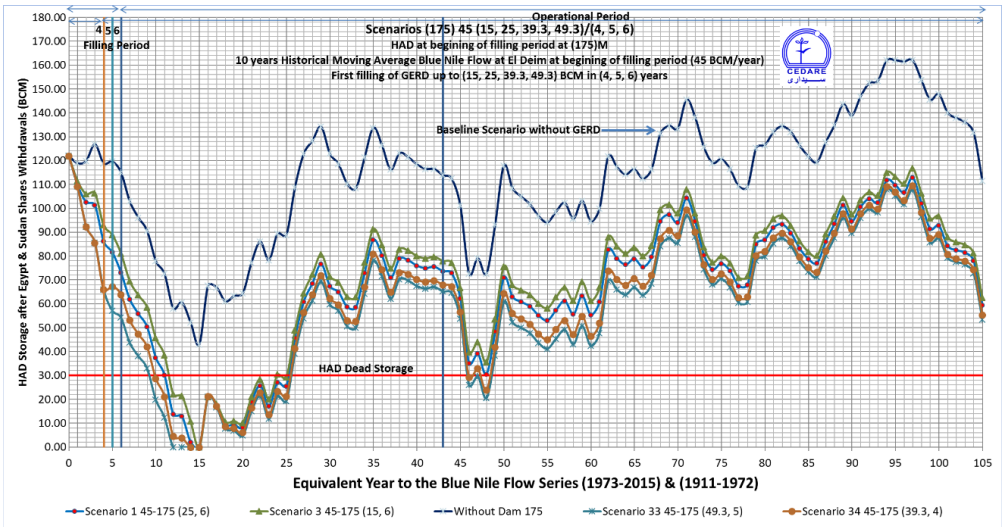

Figure 13: Scenarios (175) 45 (15, 25, 39.3, 49.3) / (4, 5, 6)

The following graph in Figure 14 shows a range of scenarios for mainly testing for the first filling, but also included subsequent operation for a 10-year average of Blue Nile flows of about 50 BCM/year at the beginning of the first filling. This range of scenarios shows start of filling when HAD level is at 175 m which is likely to happen. It shows scenarios of first filling of volumes up to 15 BCM, 18.4 BCM, 25 BCM, 28.9 BCM, 39.3 BCM and 49.3 BCM. Filling periods ranged from 2, 3, 4, 5 to 6 years. Subsequent operational rules for each "first filling scenario" were based on storing the flood flows, which mainly comes during the months of July, August and September, then releasing the stored waters throughout the same hydrological year, until the storage volume returns back to the first filling volume for that scenario. The impact on Egypt and Sudan appears when HAD level goes below the HAD "Dead Storage" level of 31 BCM. The analysis of these particular scenarios shows that the impact of first filling will start to show during the 43rd year which is after the end of the filling period by 37 years at least. It shows that the impacts on Egypt and Sudan's shares extend for about 17 years that are not during the filling period. This is mainly associated with the series of drought years of the Blue Nile and attributed to the accumulated evaporation and seepage losses associated with the GERD reservoir. This becomes apparent when comparing the series of HAD levels scenario curves with GERD in place, to the Baseline Scenario curve without GERD shown in Figure 14. The analysis confirms again that for HAD starting level of 175 m, and the filling volume scenarios ranging from 15 BCM to 49.3 BCM and for first filling period of 2 to 6 years, the impact of the GERD's accumulated evaporation and seepage losses will happen during the Blue Nile series of low flow years and may not show during the filling period.

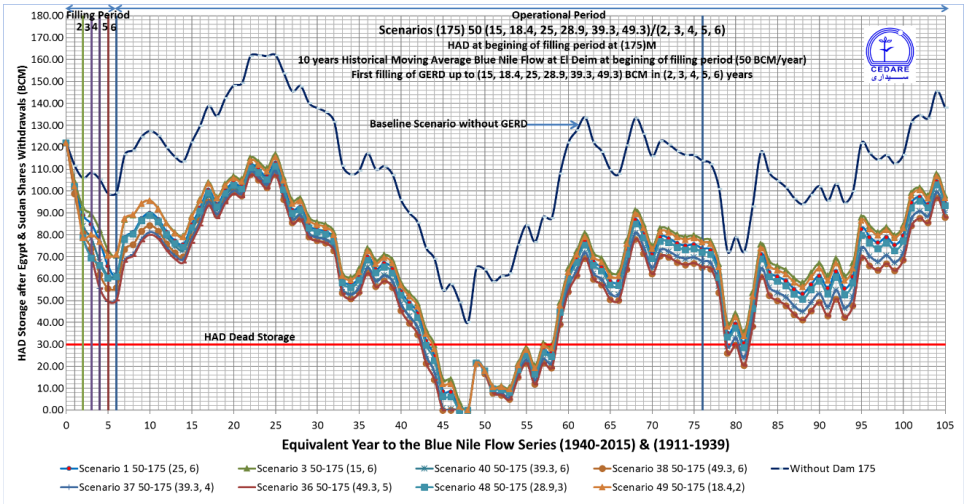

Figure 14: Scenarios (175) 50 (15, 18.4, 25, 28.9, 39.3, 49.3) / (2, 3, 4, 5, 6)

The previous analysis in Figure 14 shows also that scenarios 37 and 40 with the same first filling volume of 39.3 BCM converge to the same scenario of HAD levels after the filling period regardless of the filling duration whether it is 4 or 6 years. Scenarios 36 and 38 with the same first filling volume of 49.3 BCM also converge to the same HAD levels after the filling period regardless of the filling duration whether it is 5 or 6 years.

Impacts of Annual GERD Operation Range of (49.3 BCM – 74 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 15, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 49.3 BCM to 74 BCM of reservoir storage, where the storage goes back to the 49.3 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 17 years, starting after 35 years and reaching a total deficit of about 95 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 65.85 BCM and 74 BCM with an average of 73.91 BCM. The Average Annual GERD storage will range between 57.58 BCM and 61.65 BCM with an average of 61.6 BCM. The water levels in the HAD will go below a critical level of 167 m for 75 years in a 105 years time series, and will go below the shutdown level of 159 m for 34 years in the 105 years time series.

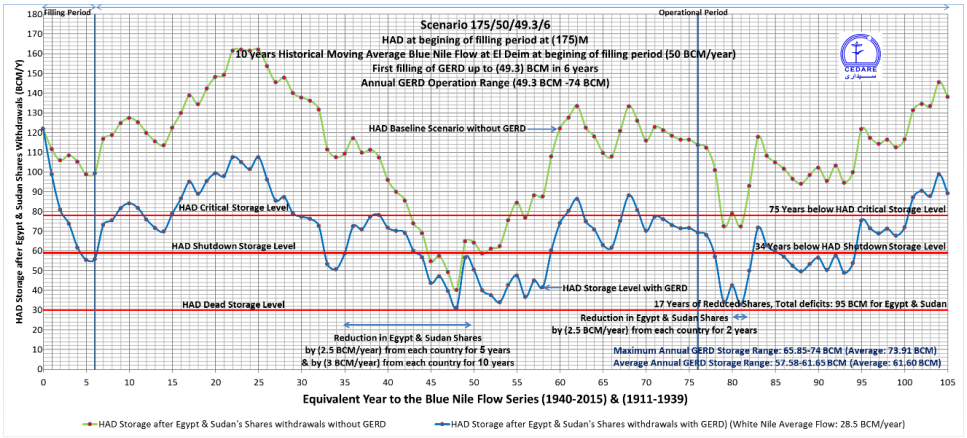

Figure 15: Scenario (175) 50 (49.3-74) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 16 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 42.86 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 80 years. Annual GERD discharges are expected to go below 40 BCM/y for 41 years, below 35 BCM/y for 19 years and below 31 BCM/y for 7 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 63.97 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 15.01 BCM/y down from 20.69 BCM/y at ElDeim. Figure 17 shows the expected GERD operational levels and ranges of operation.

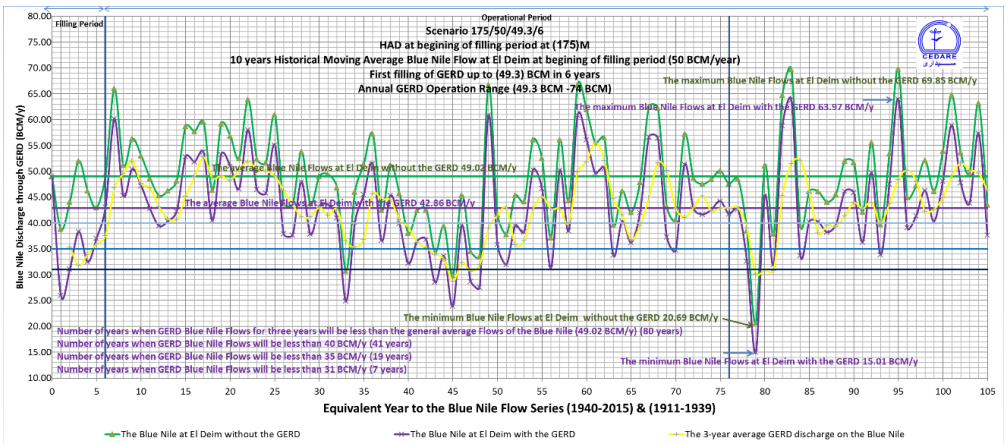

Figure 16: Blue Nile GERD Discharge Scenario (175) 50 (49.3-74) / (6)

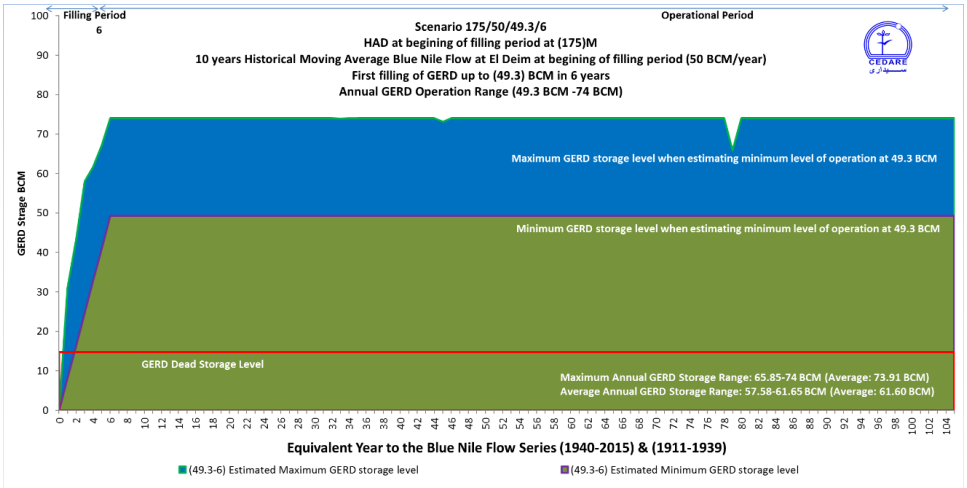

Figure 17: Expected GERD Operational Levels Scenario (175) 50 (49.3-74) / (6)

Impacts of Annual GERD Operation Range of (49.3 BCM – 60.6 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 18, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 49.3 BCM to 60.6 BCM of reservoir storage, where the storage goes back to the 49.3 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 15 years, starting after 36 years and reaching a total deficit of about 82 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will be capped at 60.6 BCM which will result in an annual average of 60.6 BCM over the years. The Average Annual GERD storage will be at 54.95 BCM with an annual average of 54.95 BCM over the years. The water levels in the HAD will go below a critical level of 167 m for 70 years in a 105 years time series, and will go below the shutdown level of 159 m for 33 years in the 105 years time series.

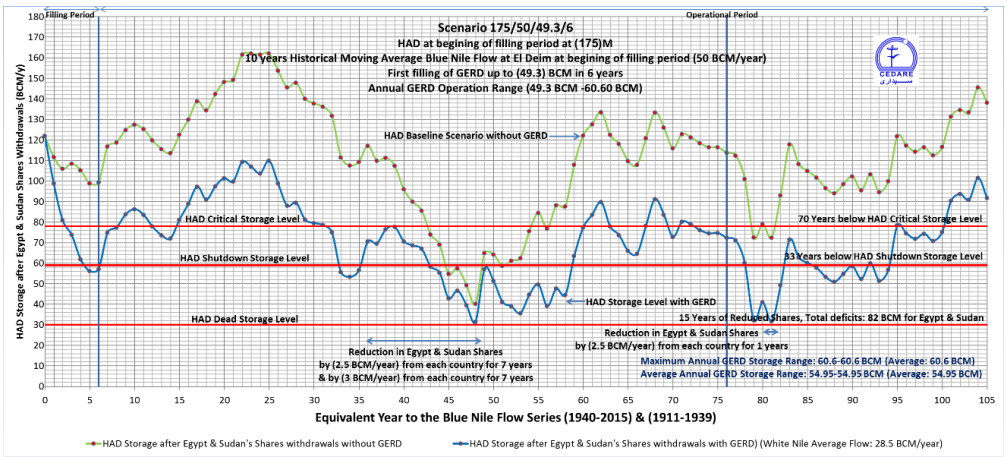

Figure 18: Scenario (175) 50 (49.3-60.6) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 19 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 43.19 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 80 years. Annual GERD discharges are expected to go below 40 BCM/y for 39 years, below 35 BCM/y for 18 years and below 31 BCM/y for 7 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 64.31 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 15.15 BCM/y down from 20.69 BCM/y at ElDeim. Figure 20 shows the expected GERD operational levels and ranges of operation.

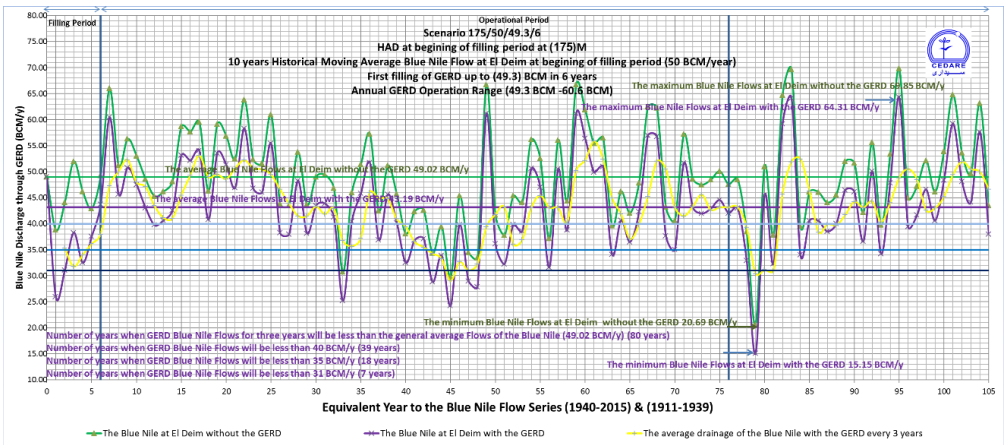

Figure 19: Blue Nile GERD Discharge Scenario (175) 50 (49.3-60.6) / (6)

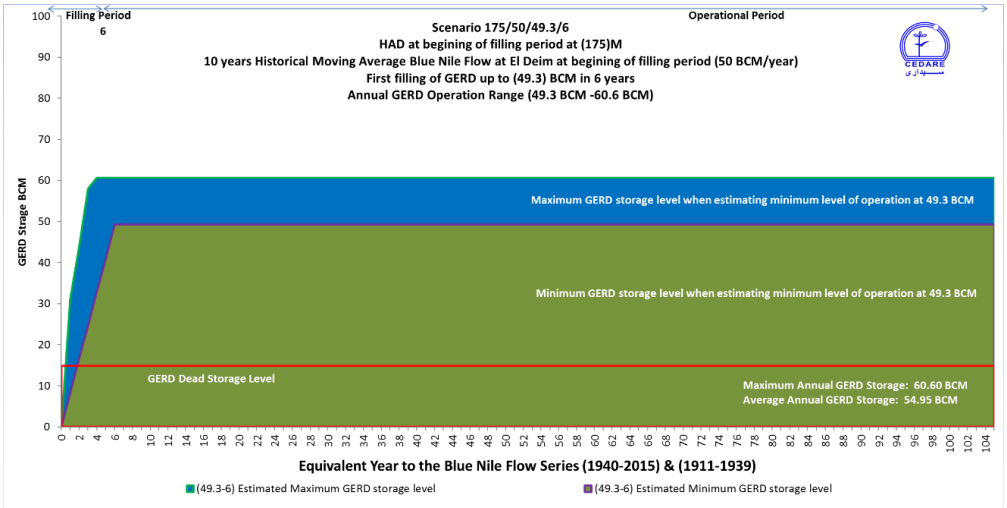

Figure 20: Expected GERD Operational Levels Scenario (175) 50 (49.3-60.6) / (6)

Impacts of Annual GERD Operation Range of (39.3 BCM – 74 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 21, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 39.3 BCM to 74 BCM of reservoir storage, where the storage goes back to the 39.3 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 15 years, starting after 36 years and reaching a total deficit of about 82 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 55.85 BCM and 74 BCM with an average of 72.96 BCM. The Average Annual GERD storage will range between 47.58 BCM and 56.65 BCM with an average of 56.13 BCM. The water levels in the HAD will go below a critical level of 167 m for 68 years in a 105 years time series, and will go below the shutdown level of 159 m for 32 years in the 105 years time series.

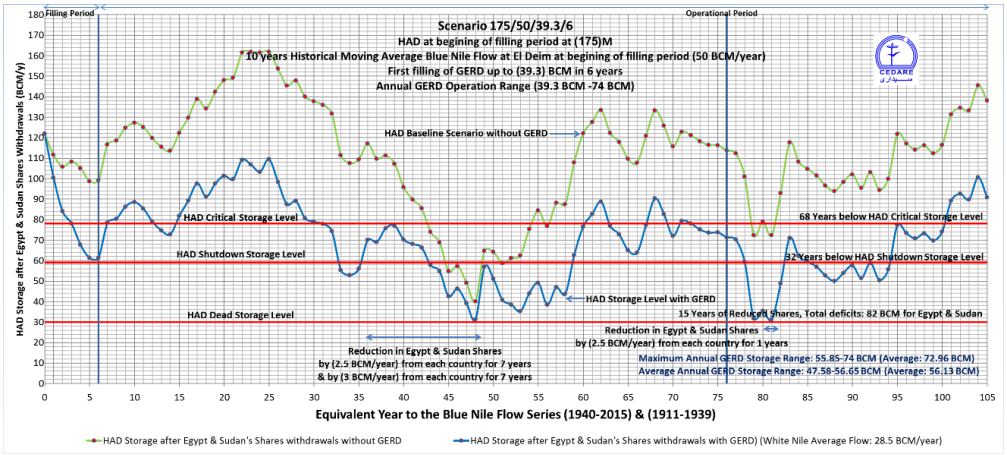

Figure 21: Scenario (175) 50 (39.3-74) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 22 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 43.18 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 80 years. Annual GERD discharges are expected to go below 40 BCM for 39 years, below 35 BCM/y for 18 years and below 31 BCM/y for 7 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 64.22 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 15.49 BCM/y down from 20.69 BCM/y at ElDeim. Figure 23 shows the expected GERD operational levels and ranges of operation.

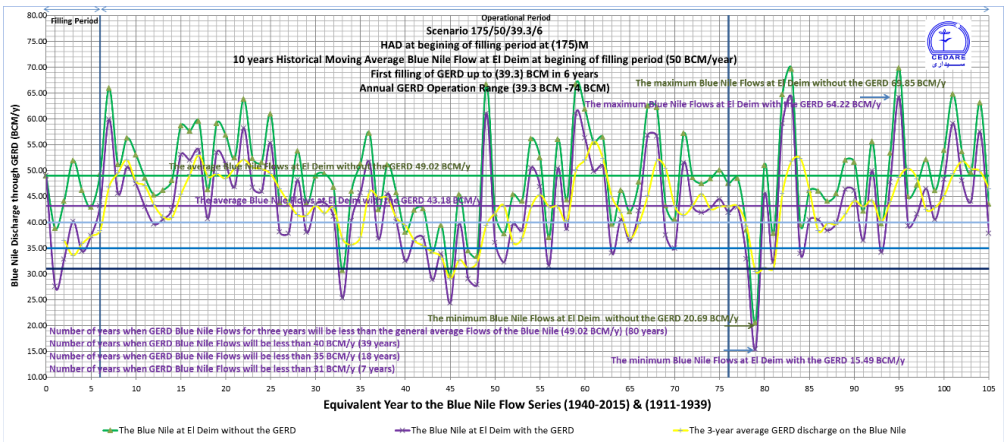

Figure 22: Blue Nile GERD Discharge Scenario (175) 50 (39.3-74) / (6)

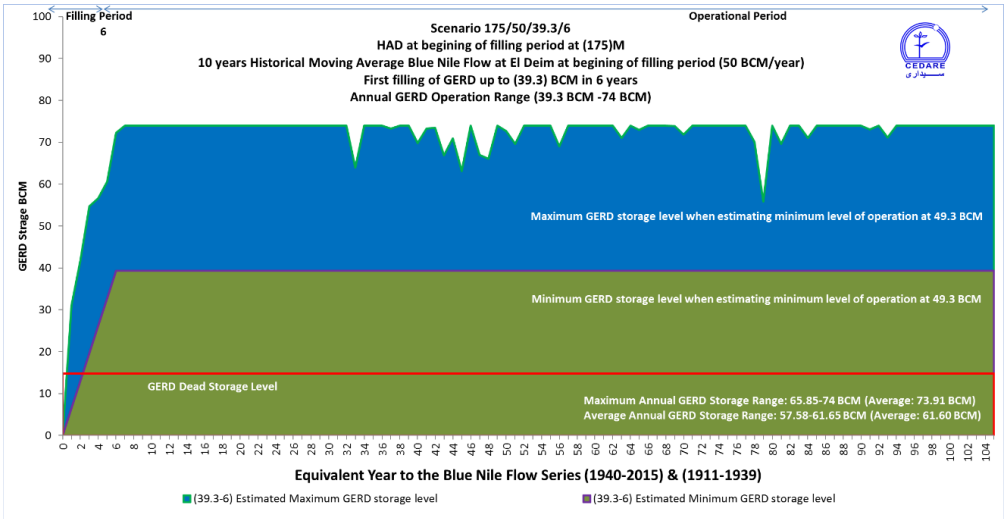

Figure 23: Expected GERD Operational Levels Scenario (175) 50 (39.3-74) / (6)

Impacts of Annual GERD Operation Range of (25 BCM – 74 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 24, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average Blue Nile flow of 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 25 BCM to 74 BCM of reservoir storage, where the storage goes back to the 25 BCM level by the end of each year. The annual deficit in this scenario is expected to be about 2.5 BCM for each country (Egypt and Sudan) for a period of 12 years, starting after 36 years and reaching a total deficit of about 60 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 41.55 BCM and 74 BCM with an average of 64 BCM. The Average Annual GERD storage will range between 33.28 BCM and 49.5 BCM with an average of 44.5 BCM. The water levels in the HAD will go below a critical level of 167 m for 57 years in a 105 years time series, and will go below the shutdown level of 159 m for 25 years in the 105 years time series.

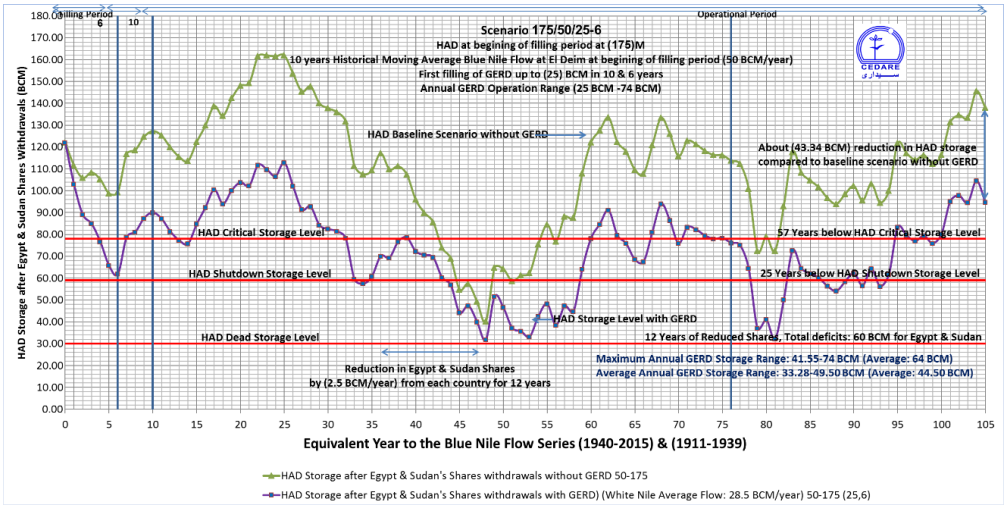

Figure 24: Scenario (175) 50 (25-74) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 25 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 43.73 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 80 years. Annual GERD discharges are expected to go below 40 BCM/y for 35 years, below 35 BCM/y for 17 years and below 31 BCM/y for 7 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 64.55 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 16.16 BCM/y down from 20.69 BCM/y at ElDeim. Figure 26 shows the expected GERD operational levels and ranges of operation.

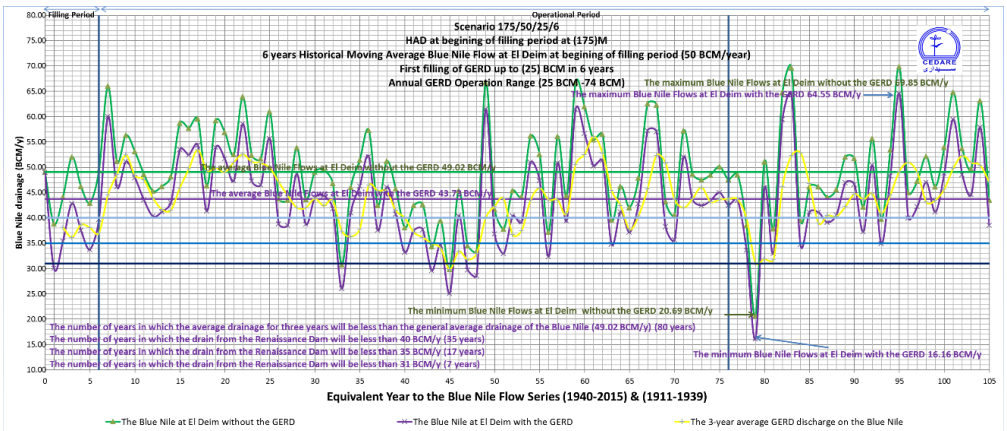

Figure 25: Blue Nile GERD Discharge Scenario (175) 50 (25-74) / (6)

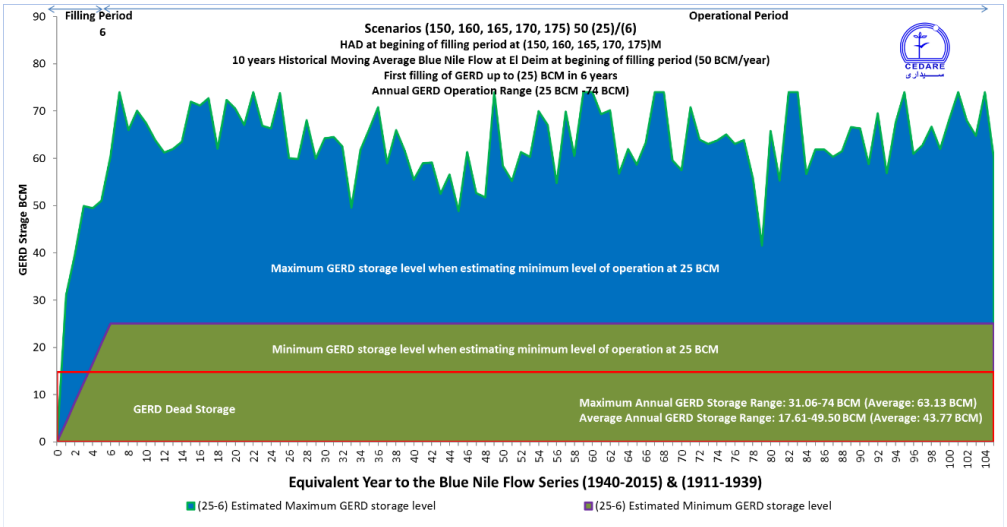

Figure 26: Expected GERD Operational Levels Scenario (175) 50 (25-74) / (6)

Impacts of Annual GERD Operation Range of (18.4 BCM – 74 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 27, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 18.4 BCM to 74 BCM of reservoir storage, where the storage goes back to the 18.4 BCM level by the end of each year. The annual deficit in this scenario is expected to be about 3 BCM for each country (Egypt and Sudan) for a period of 8 years, starting after 41 years and reaching a total deficit of about 48 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 65.85 BCM and 74 BCM with an average of 73.91 BCM. The Average Annual GERD storage will range between 57.58 BCM and 61.65 BCM with an average of 61.60 BCM. The water levels in the HAD will go below a critical level of 167 m for 51 years in a 105 years time series, and will go below the shutdown level of 159 m for 23 years in the 105 years time series.

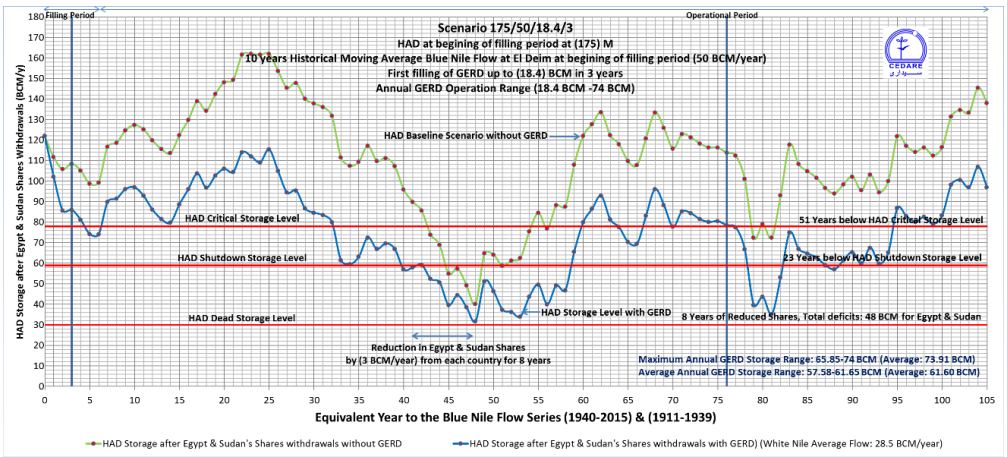

Figure 27: Scenario (175) 50 (18.4-74) / (3) with Deficit in the Shares of Egypt and Sudan

Figure 28 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 44.13 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 78 years. Annual GERD discharges are expected to go below 40 BCM/y for 33 years, below 35 BCM/y for 18 years and below 31 BCM/y for 7 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 64.70 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 16.54 BCM/y down from 20.69 BCM/y at ElDeim. Figure 29 shows the expected GERD operational levels and ranges of operation.

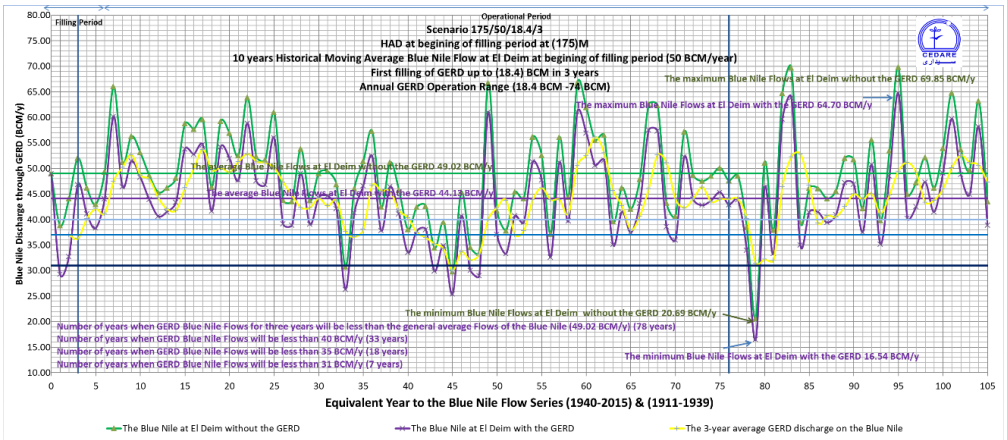

Figure 28: Blue Nile GERD Discharge Scenario (175) 50 (18.4-74) / (3)

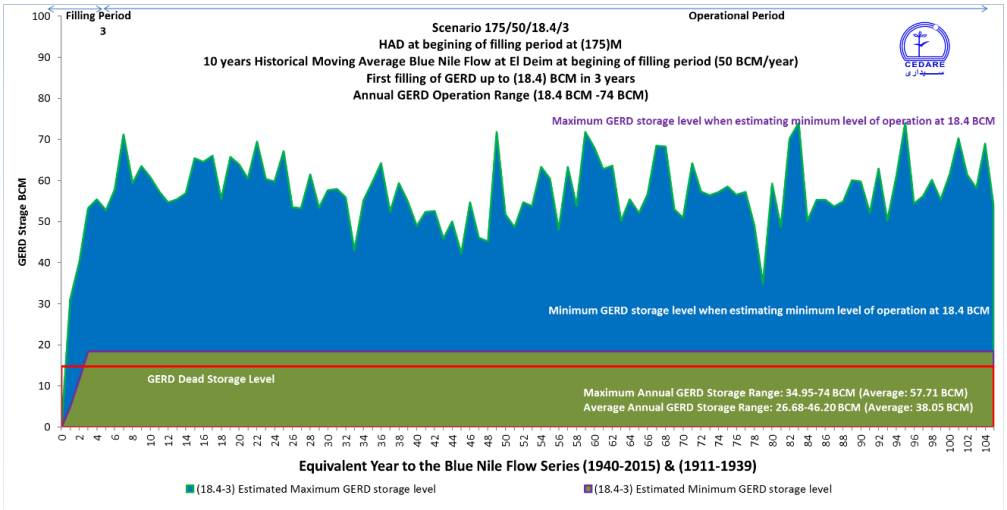

Figure 29: Expected GERD Operational Levels Scenario (175) 50 (18.4-74) / (3)

Impacts of Annual GERD Operation Range of (15 BCM – 70.88 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 30, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 15 BCM to 70.88 BCM of reservoir storage, where the storage goes back to the 15 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 9 years, starting after 41 years and reaching a total deficit of about 47 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 31.55 BCM and 70.88 BCM with an average of 54.38 BCM. The Average Annual GERD storage will range between 23.28 BCM and 42.94 BCM with an average of 34.69 BCM. The water levels in the HAD will go below a critical level of 167 m for 48 years in a 105 years time series, and will go below the shutdown level of 159 m for 24 years in the 105 years time series.

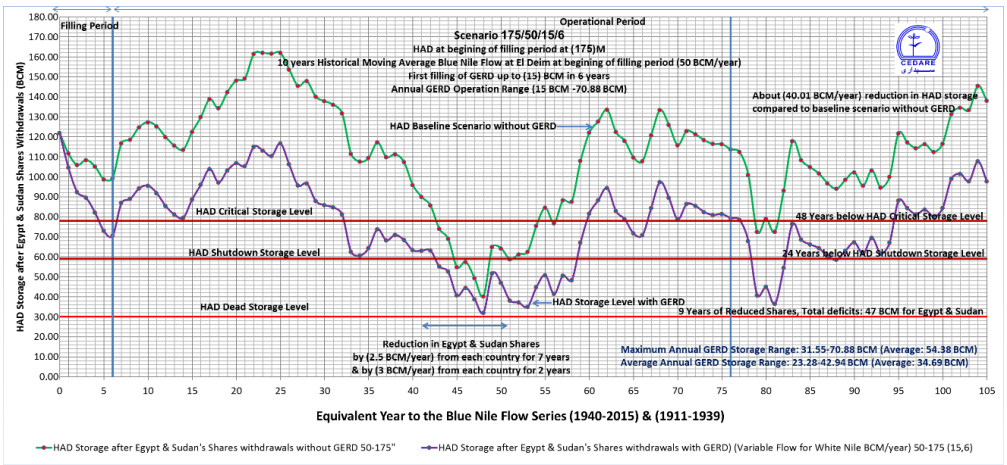

Figure 30: Scenario (175) 50 (15-70.88) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 31 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 44.27 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 78 years. Annual GERD discharges are expected to go below 40 BCM/y for 34 years, below 35 BCM/y for 12 years and below 31 BCM/y for 6 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 64.25 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 16.72 BCM/y down from 20.69 BCM/y at ElDeim. Figure 32 shows the expected GERD operational levels and ranges of operation.

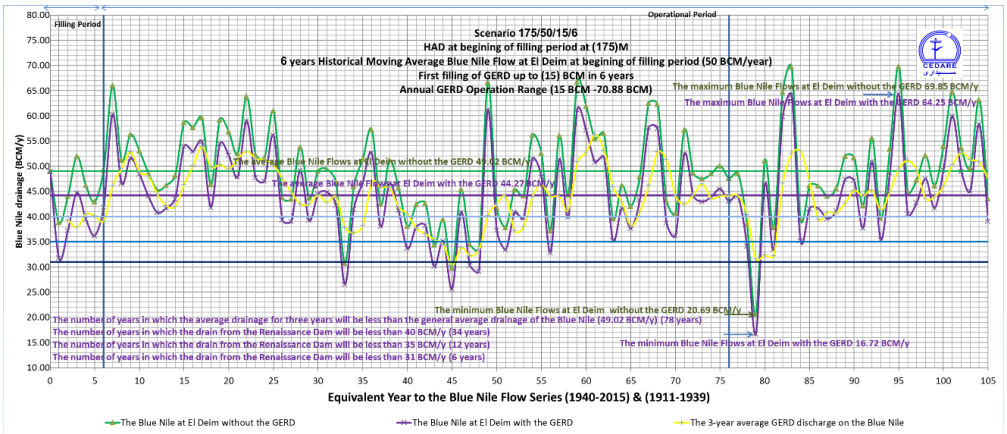

Figure 31: Blue Nile GERD Discharge Scenario (175) 50 (15-70.88) / (6)

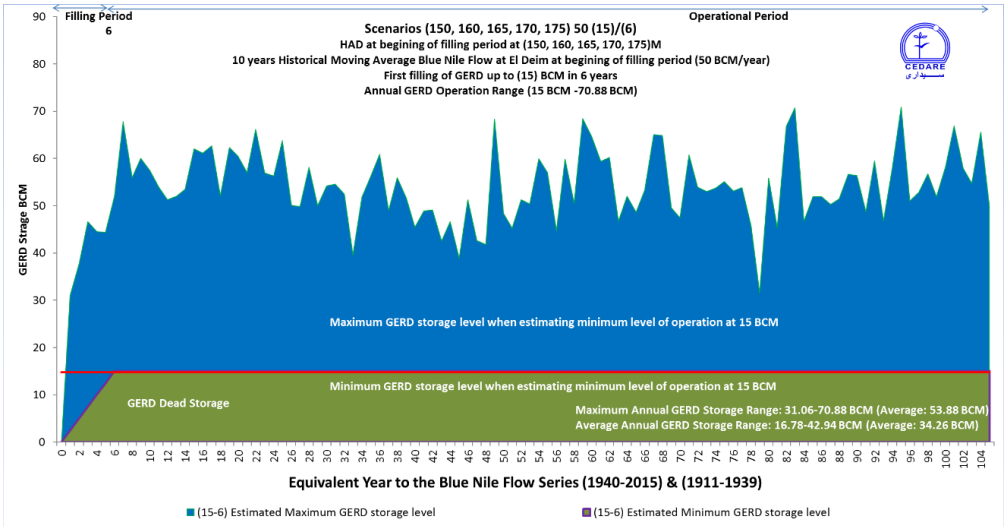

Figure 32: Expected GERD Operational Levels Scenario (175) 50 (15-70.88) / (6)

Impacts of Annual GERD Operation Range of (15 BCM – 60.6 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 33 below, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 15 BCM to 60.6 BCM of reservoir storage, where the storage goes back to the 15 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 9 years, starting after 40 years and reaching a total deficit of about 46 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 31.35 BCM and 60.6 BCM with an average of 53.49 BCM. The Average Annual GERD storage will range between 23.28 BCM and 37.80 BCM with an average of 34.25 BCM. The water levels in the HAD will go below a critical level of 167 m for 48 years in a 105 years time series, and will go below the shutdown level of 159 m for 20 years in the 105 years time series.

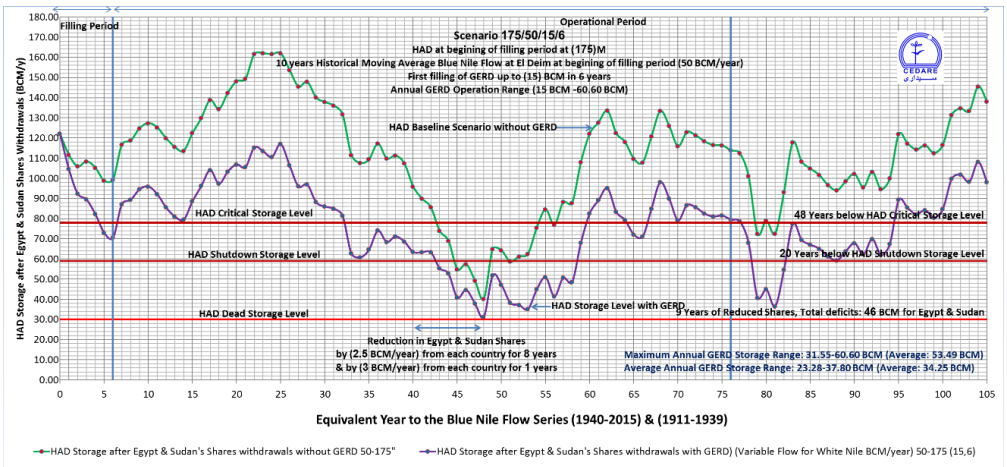

Figure 33: Scenario (175) 50 (15-60.6) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 34 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 44.32 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 78 years. Annual GERD discharges are expected to go below 40 BCM/y for 34 years, and below 35 BCM/y for 12 years and below 31 BCM/y for 6 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 65.13 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 16.72 BCM/y down from 20.69 BCM/y at ElDeim. Figure 35 shows the expected GERD operational levels and ranges of operation.

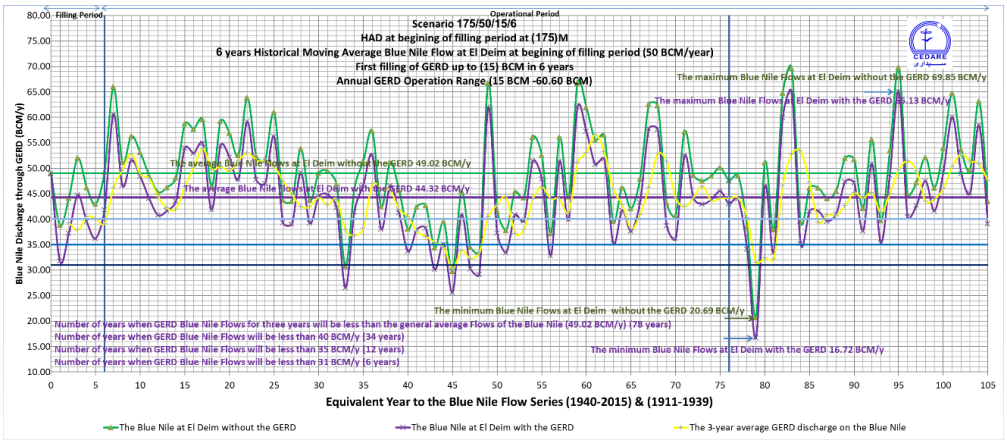

Figure 34: Blue Nile GERD Discharge Scenario (175) 50 (15-60.6) / (6)

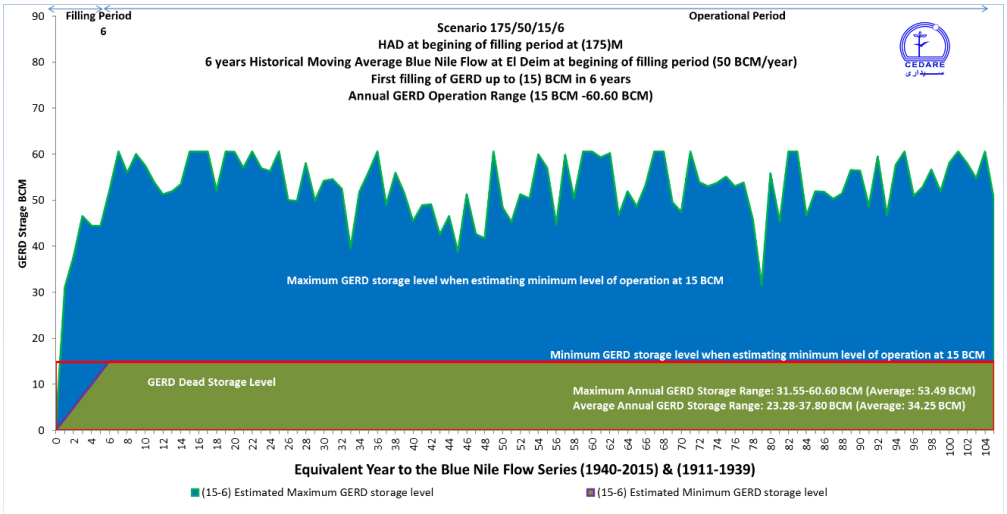

Figure 35: Expected GERD Operational Levels Scenario (175) 50 (15-60.6) / (6)

Impacts of Annual GERD Operation Range of (15 BCM – 49.3 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 36, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 15 BCM to 49.3 BCM of reservoir storage, where the storage goes back to the 15 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 8 years, starting after 41 years and reaching a total deficit of about 44 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 31.55 BCM and 49.3 BCM with an average of 48.35 BCM. The Average Annual GERD storage will range between 23.28 BCM and 32.15 BCM with an average of 31.68 BCM. The water levels in the HAD will go below a critical level of 167 m for 47 years in a 105 years time series, and will go below the shutdown level of 159 m for 20 years in the 105 years time series.

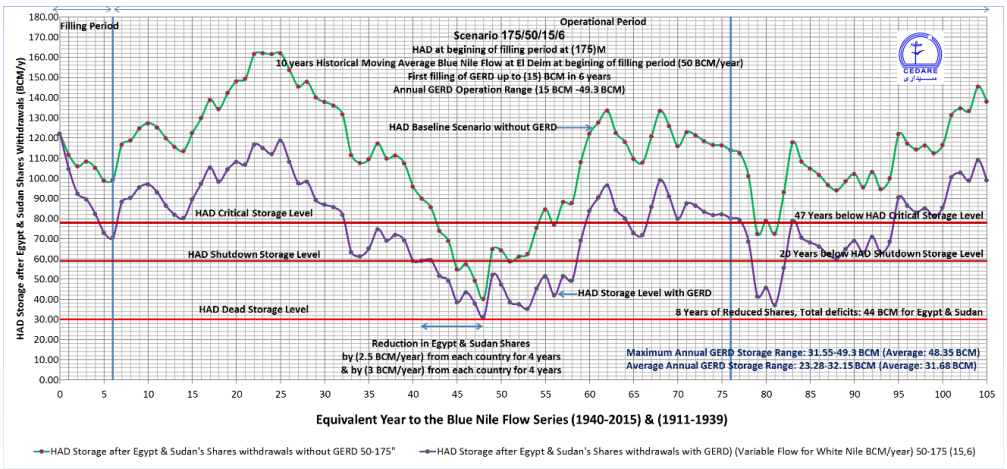

Figure 36: Scenario (175) 50 (15-49.3) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 37 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 44.43 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 77 years. Annual GERD discharges are expected to go below 40 BCM/y for 34 years, below 35 BCM/y for 12 years and below 31 BCM/y for 6 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 65.37 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 16.72 BCM/y down from 20.69 BCM/y at ElDeim. Figure 38 shows the expected GERD operational levels and ranges of operation.

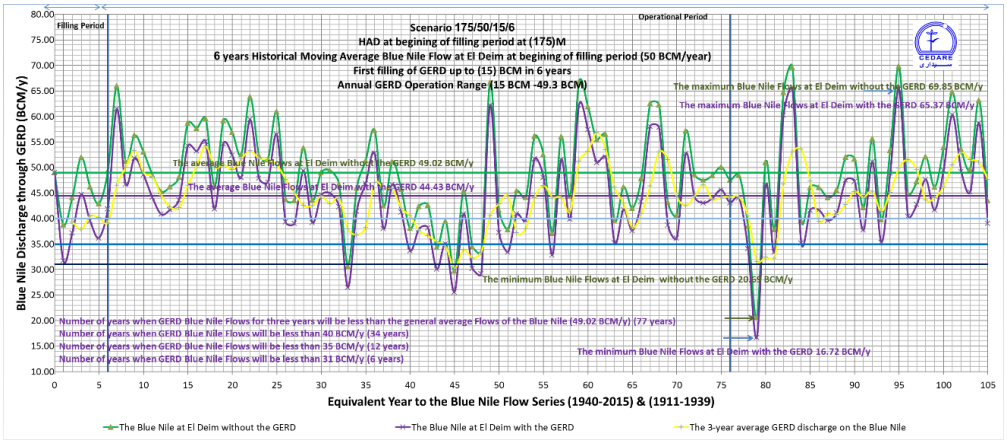

Figure 37: Blue Nile GERD Discharge Scenario (175) 50 (15-49.3) / (6)

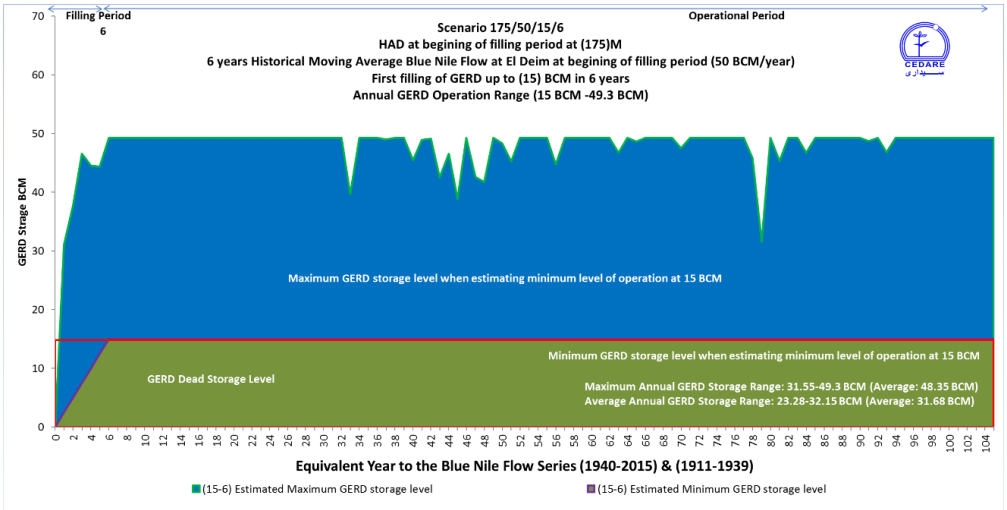

Figure 38: Expected GERD Operational Levels Scenario (175) 50 (15-49.3) / (6)

Impacts of Annual GERD Operation Range of (15 BCM – 39.3 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 39, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 15 BCM to 39.3 BCM of reservoir storage, where the storage goes back to the 15 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 8 years, starting after 41 years and reaching a total deficit of about 41 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will range between 31.55 BCM and 39.3 BCM with an average of 39.22 BCM. The Average annual GERD storage will range between 23.28 BCM and 27.5 BCM with an average of 27.11 BCM. The water levels in the HAD will go below a critical level of 167 m for 47 years in a 105 years time series, and will go below the shutdown level of 159 m for 20 years in the 105 years time series.

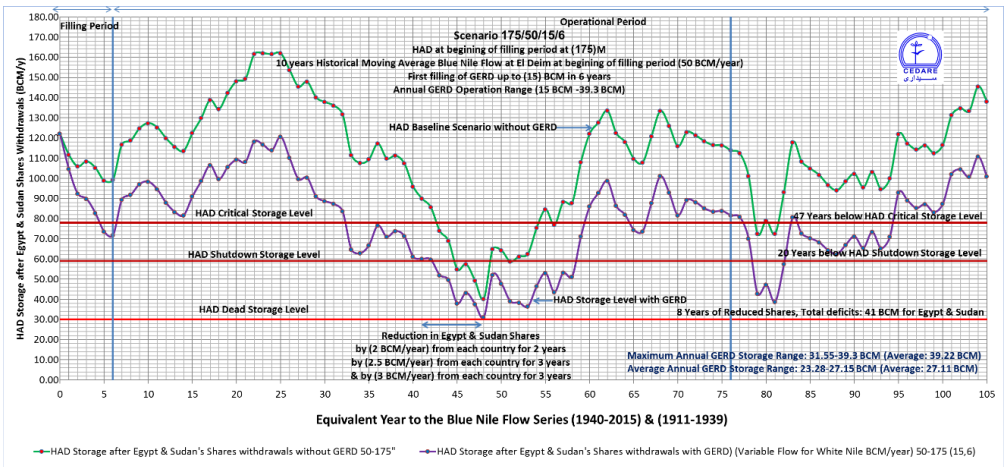

Figure 39: Scenario (175) 50 (15-39.3) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 40 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 44.67 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 76 years. Annual GERD discharges are expected to go below 40 BCM/y for 33 years, below 35 BCM/y for 12 years and below 31 BCM/y for 6 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 65.64 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be 16.72 BCM/y down from 20.69 BCM/y at ElDeim. Figure 41 shows the expected GERD operational levels and ranges of operation.

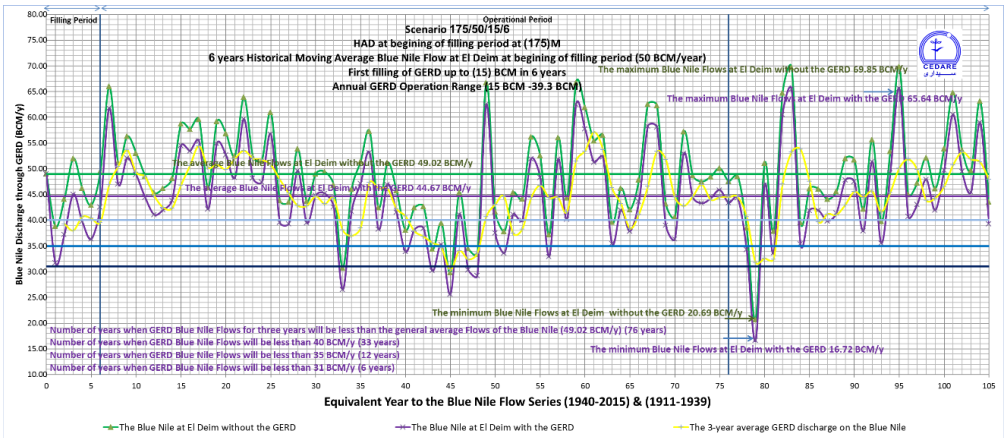

Figure 40: Blue Nile GERD Discharge Scenario (175) 50 (15-39.3) / (6)

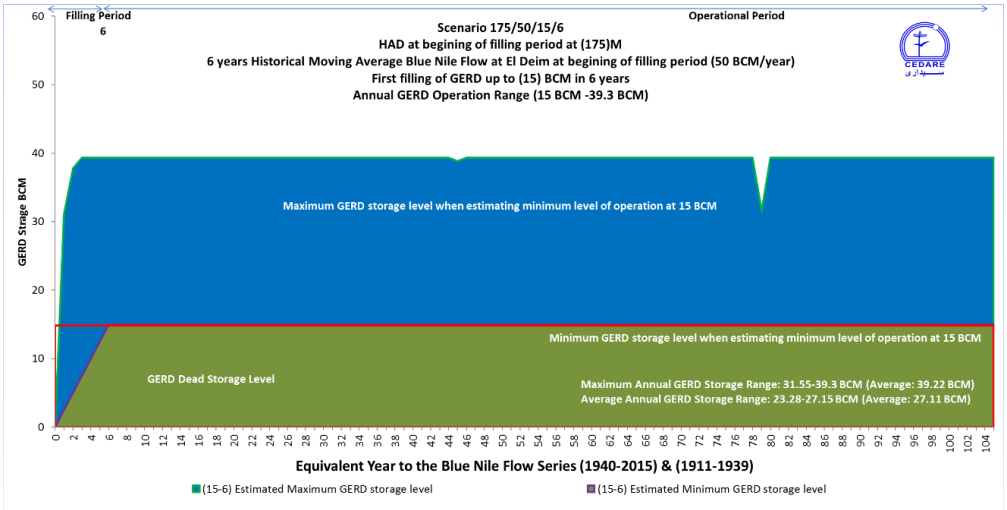

Figure 41: Expected GERD Operational Levels Scenario (175) 50 (15-39.3) / (6)

Impacts of Annual GERD Operation Range of (15 BCM – 18.4 BCM) after Filling During a 10-Year Average Flow of 50 BCM/y

As shown in Figure 42, this scenario assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 50 BCM/year (similar to that which occurred in the period from 1940 to 1949), and coinciding with a HAD reservoir level at the beginning of this series at about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual GERD operation range is from 15 BCM to 18.4 BCM of reservoir storage, where the storage goes back to the 15 BCM level by the end of each year. The annual deficit in this scenario is expected to be between 2.5 BCM and 3 BCM for each country (Egypt and Sudan) for a period of 6 years, starting after 42 years and reaching a total deficit of about 33 BCM for both countries. For this scenario, the Maximum Annual GERD storage during the period of 105 years of simulated historical flows will be about 18.4 BCM with an average of 18.4 BCM. The Average Annual GERD storage will be about 16.7 BCM with an average of 16.7 BCM. The water levels in the HAD will go below a critical level of 167 m for 41 years in a 105 years time series, and will go below the shutdown level of 159 m for 19 years in the 105 years time series.

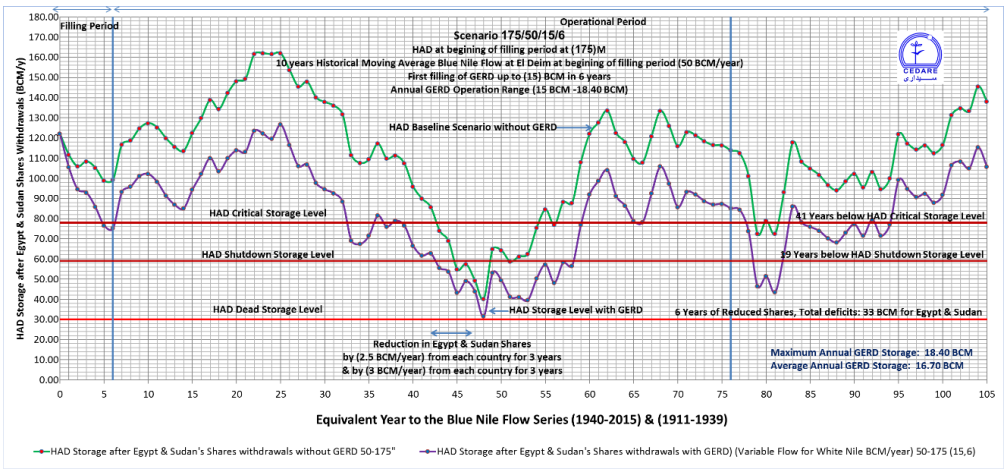

Figure 42: Scenario (175) 50 (15-18.4) / (6) with Deficit in the Shares of Egypt and Sudan

Figure 43 shows the expected Blue Nile discharges through GERD that will be associated with this scenario of operational rules. Average Annual GERD discharge over the simulated period of 105 years is expected to be 45.33 BCM/y down from 49.02 BCM/y of Average Blue Nile Natural flow. During this period, 3-year Annual Average GERD discharges are expected to go below the long-term average Blue Nile Natural Flow of 49.02 BCM/y for 75 years. Annual GERD discharges is expected to go below 40 BCM/y for 28 years, below 35 BCM/y for 12 years and below 31 BCM/y for 6 years. The maximum Annual Blue Nile flow at ElDeim station is expected to be about 66.29 BCM/y down from 69.85 BCM/y, and the minimum Annual Blue Nile flow is expected to be about 17.13 BCM/y down from 20.69 BCM/y at ElDeim. Figure 44 shows the expected GERD operational levels and ranges of operation.

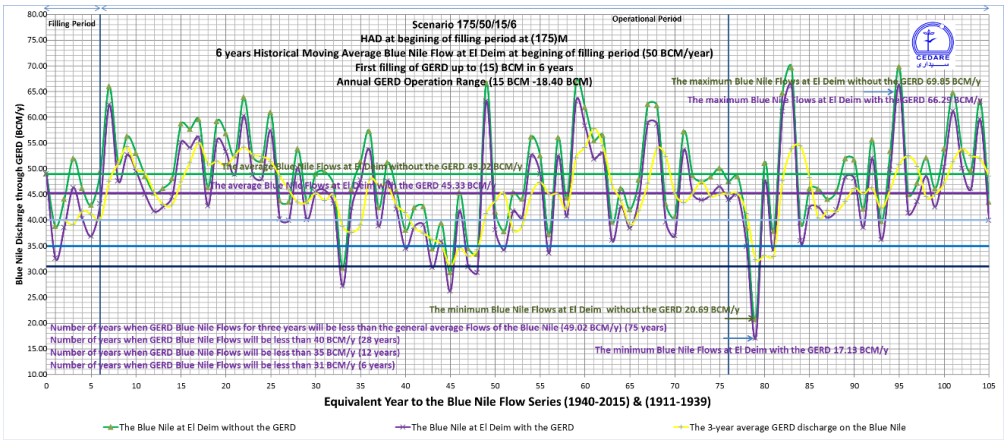

Figure 43: Blue Nile GERD Discharge Scenario (175) 50 (15-18.4) / (6)

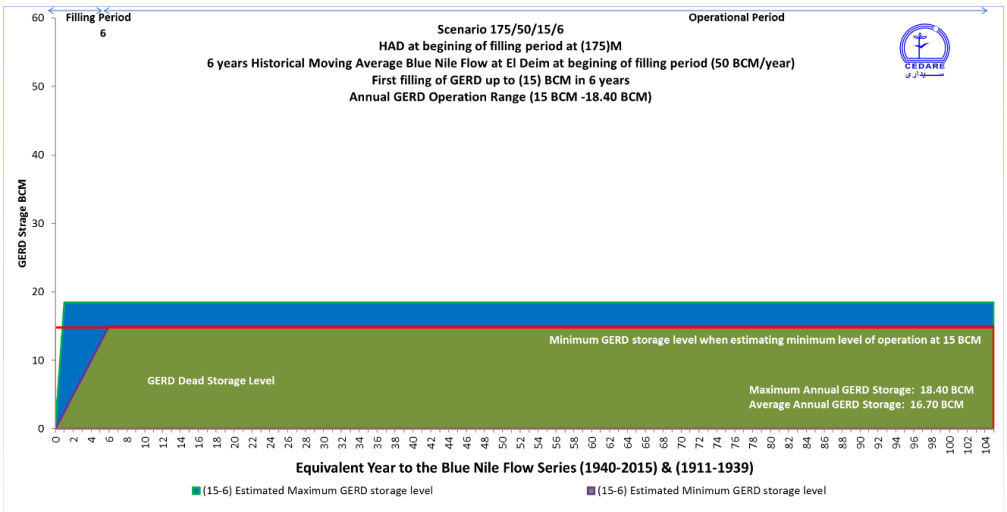

Figure 44: Expected GERD Operational Levels Scenario (175) 50 (15-18.4) / (6)

Deficits Years and Volumes for Selected GERD Filling and Operation Scenarios

The table in Figure 45 shows a summary of the previous analysis showing number of water deficit years and volumes of deficit in satisfying Egypt and Sudan's Nile water shares for the 10 selected scenarios. It is based on simulated historical series of flows used during the "operating period" after "first filling" for the 10 scenarios of operating ranges between 15 BCM and 74 BCM with a common "First Filling Rule" of filling to a size equal to the lower end of the operating range, and a common "Operating Rule" thereafter of free additional filling through the flood period conditioned by releasing the entire annual flood volume throughout the hydrological year, and returning back, by the end of the hydrological year, to the minimum operating level which is the lower end of the operating range which is equivalent to the size of the "First Filling".

Average Blue Nile flows in the first 10 years of GERD filling and operation (50 BCM/year), Filling Period is (3-6 Years)	Water level in front of HAD at the beginning of time series at 175 m			Total Deficit Volume (BCM/y) per each country (Egypt & Sudan)	Total Deficit Volume (BCM/y) for both countries (Egypt & Sudan)	Average Blue Nile flows in the first 10 years of GERD filling and operation (50 BCM/year), Filling Period is (6 Years)	Water level in front of HAD at the beginning of time series at 175 m				Total Deficit Volume (BCM/y) per each country (Egypt & Sudan)	Total Deficit Volume (BCM/y) for both countries (Egypt & Sudan)
	Withdrawals by Egypt and Sudan						Withdrawals by Egypt and Sudan					
	53	52.5	Egypt				53.5	53	52.5	Egypt		
GERD Operating Range Scenarios	16	15.5	Sudan			GERD Operating Range Scenarios	16.5	16	15.5	Sudan		
	Deficit Volume (BCM/year/each country)						Deficit Volume (BCM/year/each country)					
	2.5	3					2	2.5	3			
	Deficit Years		Total				Deficit Years			Total		
49.3 BCM - 74 BCM	7	10	17	47.5	95	15 BCM - 70.88 BCM		7	2	9	23.5	47
49.3 BCM - 60.6 BCM	8	7	15	41	82	15 BCM - 60.6 BCM		8	1	9	23	46
39.3 BCM - 74 BCM	8	7	15	41	82	15 BCM - 49.3 BCM		4	4	8	22	44
25 BCM - 74 BCM	12		12	30	60	15 BCM - 39.3 BCM	2	3	3	8	20.5	41
18.4 BCM - 74 BCM		8	8	24	48	15 BCM - 18.4 BCM		3	3	6	16.5	33

Figure 45: Egypt & Sudan Deficit Years & Volumes for GERD Operating Range Scenarios

Analysis of the results shown in the table in Figure 45 shows that the GERD Operating Range Scenario of 49.3 BCM to 74 BCM gives the largest negative hydrological impacts on water availability for downstream Sudan and Egypt where there is a total of about 95 BCM of deficit volume during the 105 years of simulation. There will be a total of about 17 years of water shortage of 2.5 BCM to 3.0 BCM of annual deficit in satisfying each of Egypt's and Sudan's shares. Each country may suffer a total deficit of about 47.5 BCM during the 105 years after the start of filling and operation of GERD. The GERD Operating Range Scenario of 15 BCM to 18.4 BCM gives the least negative hydrological impacts on water availability for downstream Sudan and Egypt where there is a total of about 33 BCM of deficit volume during the 105 years of simulation. There will be a total of about 6 years of water shortage of 2.0 BCM to 3.0 BCM of annual deficit in satisfying each of Egypt's and Sudan's shares. Each country may suffer of a total deficit of about 16.5 BCM during the 105 years after the start of filling and operation of GERD.

The GERD Impacts on the Blue Nile Discharge Downstream

The table in Figure 46 summarizes the expected GERD annual discharges downstream under each of the 10 GERD Operating Range Scenarios compared to the Natural Blue Nile flows and compared to other thresholds. It shows the number of years where the GERD discharge goes below the long-term annual average Blue Nile flow of 49.02 BCM/y during the simulated 105 years. It also shows how many years the GERD discharge will go below the thresholds of 40 BCM/y, 35 BCM/y and 31 BCM/y.

From the scenario comparison shown in Figure 46, it shows that the Operating Range Scenario (49.3 BCM-74 BCM) results in the largest impact on the GERD Average Annual Discharge downstream reducing it to about 42.86 BCM/y down by an average of about 6.16 BCM/y from the Average Natural Blue Nile flow of 49.02 BCM/y. In that scenario, 3-year Annual Average GERD Discharge is expected to go below the Average Natural Blue Nile flow of 49.02 BCM/y for about 80 years out of the next 105 years. Annual GERD Discharge is expected to go below the threshold of 40 BCM/y for about 41 years, below the threshold of 35 BCM/y for about 19 years, and below the threshold of 31 BCM/y for about 7 years during the 105 years following the start of filling and operation.

Operating Range Scenario (15 BCM-18.4 BCM) results in the least impact on the GERD Average Annual Discharge downstream reducing it to about 45.33 BCM/y down by an average of about 3.69 BCM/y from the Average Natural Blue Nile flow of 49.02 BCM/y. In that scenario, 3-year Annual Average GERD Discharge is expected to go below the Average Natural Blue Nile flow of 49.02 BCM/y for about 75 years out of the next 105 years. Annual GERD Discharge is expected to go below the threshold of 40 BCM/y for about 28 years, below the threshold of 35 BCM/y for about 12 years, and below the threshold of 31 BCM/y for about 6 years during the 105 years following the start of filling and operation.

Average Blue Nile flows in the first 10 years of filling and operation (50 BCM/year), Filling Period is (3-6 Years)	Average Annual GERD Discharge Compared to Average Natural Blue Nile Flow of 49.02 BCM/y	Number of Years GERD Annual Discharge below Thresholds in 105 years				Average Blue Nile flows in the first 10 years of filling and operation (50 BCM/year), Filling Period is (6 years)	Average Annual GERD Discharge Compared to Average Natural Blue Nile Flow of 49.02 BCM/y	Number of Years GERD Annual Discharge below Thresholds in 105 years			
GERD Operating Range Scenarios		3-Year Average GERD Discharge below Average Natural Blue Nile Flow (49.02 BCM/y)	Annual GERD Discharge below 40 BCM/y	Annual GERD Discharge below 35 BCM/y	Annual GERD Discharge below 31 BCM/y	GERD Operating Range Scenarios		3-Year Average GERD Discharge below Average Natural Blue Nile Flow (49.02 BCM/y)	Annual GERD Discharge below 40 BCM/y	Annual GERD Discharge below 35 BCM/y	Annual GERD Discharge below 31 BCM/y
49.3 BCM - 74 BCM	42.86	80	41	19	7	15 BCM - 70.88 BCM	44.27	78	34	12	6
49.3 BCM - 60.6 BCM	43.19	80	39	18	7	15 BCM - 60.6 BCM	44.32	78	34	12	6
39.3 BCM - 74 BCM	43.18	80	39	18	7	15 BCM - 49.3 BCM	44.43	77	34	12	6
25 BCM - 74 BCM	43.73	80	35	17	7	15 BCM - 39.3 BCM	44.67	76	33	12	6
18.4 BCM - 74 BCM	44.13	78	33	18	7	15 BCM - 18.4 BCM	45.33	75	28	12	6

Figure 46: GERD Annual Discharge below Threshold at Different GERD Operating Ranges

The GERD Impacts on the HAD Hydropower

The greatest factor affecting the fulfillment of the shares of Egypt and Sudan from the Nile in the presence of GERD is the average annual storage volume of the GERD and the accumulative evaporation and seepage losses from GERD reservoir. The storage volume is assumed to return back at the end of the hydrological year to the minimum storage of the "first filling" to

accommodate the next year's flood. The smaller this storage is, the greater the reduction in the evaporation and seepage losses from the GERD reservoir and the smaller the impact on the flows downstream to Egypt and Sudan. Thus, the best scenario for the operation was found to be where the GERD reservoir at the end of the hydrological year would return to 15 BCM at a level of about 590 m where the top 11 turbines may still be operable. In some cases, especially in dry years and prolonged droughts, GERD levels may need to drop down to 4.9 BCM where the top 11 turbines may not be operable and only the two lower turbines may be operable.

As for the hydropower of the HAD, the impact on the shortage of hydropower generated from the HAD is certain, unless it is agreed to discharge the entire Blue Nile flows during the same months they arrive in, without distributing them throughout the year. However, uniform hydropower production throughout the year from GERD leads to a decrease in average water levels in the HAD, even if the three countries agreed to discharge the entire flow annually after the filling period. The HAD's hydropower may be reduced by 22 to 36 percent due to the GERD according to the scenarios presented here. Although the hydropower of the HAD does not represent a large proportion of the generated power at the national level in Egypt, yet it represents about one third of the hydropower to be generated by the GERD and contributes to the provision of electricity needs of two governorates or more in Upper Egypt.

The graph in Figure 47 shows the decrease scenarios in the average levels and contents of the HAD affecting hydropower generation due to the operation of the GERD at a minimum operating level equivalent to a storage volume ranging from 15 to 49.3 BCM and ensuring that GERD levels return to that level by the end of the hydrological year. These scenarios lead to a maximum reduction in the average reservoir storage of HAD of about 50 BCM, and a maximum drop of about 10.5 m in the average water level in the HAD. The minimum reductions are shown on the graph below to be at least 6.5 m which is equivalent to a reduction in HAD storage of about 30 BCM.

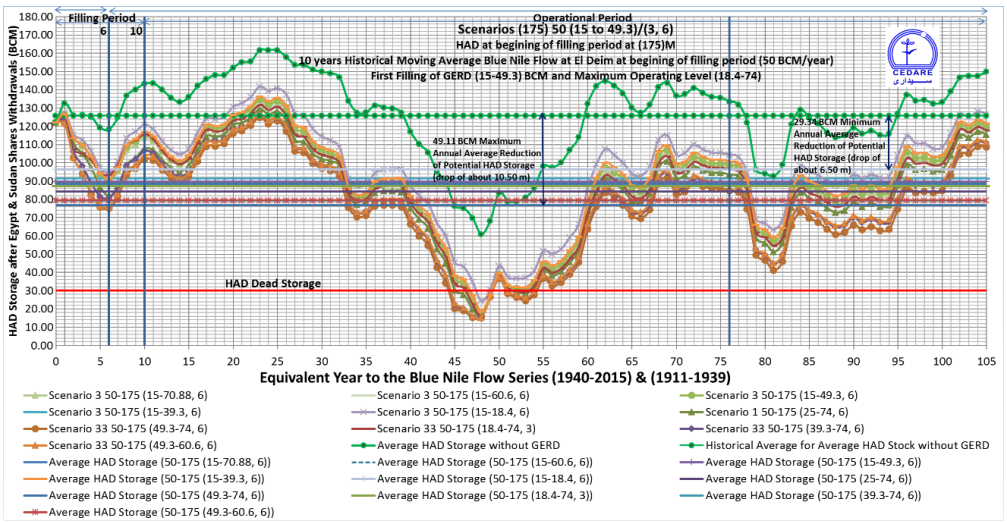

Figure 47: HAD Average Content/Level for GERD Operating Ranges (175) 50 (15-74)/ (3, 6)

The table in Figure 48 shows that the simulated scenarios result in a reduction in the hydropower generation head ranging from 22% to 36%, which will have a similar effect on the decrease in hydropower generated from the HAD due to the presence of the GERD. This is due to a decrease in the average HAD level corresponding to reductions in average storage between 30 BCM to 50 BCM.

Average flows in the first 10 years of filling and operation 50	**Minimum reduction in average HAD storage (BCM)**	**Maximum reduction in the average HAD storage (BCM)**	**Minimum reduction in the average level in the HAD (m)**	**Maximum reduction in the average level in the HAD (m)**	**Minimum percentage reduction in hydropower generation head**	**Maximum percentage reduction in hydropower generation head**
49.3 BCM - 74 BCM	**29.34**	**49.11**	**6.50**	**10.50**	**22%**	**36%**
49.3 BCM - 60.6 BCM						
39.3 BCM - 74 BCM						
25 BCM - 74 BCM						
18.4 BCM - 74 BCM						
15 BCM - 70.88 BCM						
15 BCM - 60.6 BCM						
15 BCM - 49.3 BCM						
15 BCM - 39.3 BCM						
15 BCM - 18.4 BCM						

Figure 48: Reduction in HAD Hydropower Reflected by Reduced Volumes & Levels

Conclusion

According to the assumptions used in the simulated scenarios, there will be a failure to fulfill the Nile annual shares of Egypt and Sudan in all scenarios. The largest impact on the annual shares of Egypt (55.5 BCM) and Sudan (18.5 BCM) after the completion and operation of the GERD is due to the volume of dead storage (storage above the highest level of the turbines), the first filling volume and the GERD average annual storage volume. This impact is exacerbated by the effects of the volume of evaporation and seepage losses from the GERD reservoir which represents a new change in the Nile hydrological system. The cumulative effects of those losses have a great impact on the size of the storage in the HAD Reservoir. As the annual average storage of the GERD reservoir increases, the evaporation and seepage losses from the GERD reservoir will increase. This will result in the reduction in the Blue Nile flows downstream to Egypt and Sudan. The GERD will lead to a decrease in hydropower generated from the HAD due to the operation of the HAD turbines at a lower average level than the Baseline Scenario before the construction of the GERD.

The volume of first filling (minimum operating level) of the GERD has an impact on the cumulative effect of GERD evaporation losses and seepage losses during operation. It is the major impact on the reduction of Blue Nile flows to Egypt and Sudan. The agreement on the annual operating rules is as important, if not more important, than the agreement on the first filling rules. The greatest risk may occur in the operating period as compared to the filling period and the real impact of the GERD may occur in those years following the filling period and during the operation period. In the long run, all filling scenarios of the same first filling

volume will converge to the same scenario regardless of the filling period, and the large impact of the GERD will be during the years with low natural flows of the Blue Nile.

It shows that the deficit scenarios in providing the current shares of Egypt and Sudan due to GERD will vary in time according to the impacts on Blue Nile flows and may last for periods ranging from 6 to 17 years during low-flow years.

It is unfortunate that the official joint studies that were to be conducted by the jointly-hired consortium of consulting firms has stopped due to disagreements on the inception report and on issues such as the baseline scenario, criteria for impact assessment and others. The joints studies were supposed to provide an agreed assessment of the potential impacts of GERD compared to the baseline scenario.

Recommendations

In the absence of an agreed baseline, and agreed potential impacts of the GERD, the three countries have to agree on the first filling and operating rules to minimize any negative impacts on Egypt and Sudan on one hand, and to optimize the hydropower benefits for Ethiopia on the other hand.

Egypt, Sudan and Ethiopia need to agree on the size of the first filling before talking about the filling rules. Agreement on the rules of filling should take into account the operating rules and they should be linked, where the first filling storage volume would be equal to the minimum operating level. It is recommended to study the feasibility of reducing the overall size of GERD below the current design size of 74 BCM, to ensure operating at low average levels to reduce the negative impacts on Egypt and Sudan downstream. The maximum storage capacity could be large enough only to absorb high flows during the high flood months to make use of it in power generation during the same year.

It is recommended that the volume of the first filling of the GERD should be defined as just above the dead storage known as the lowest storage above turbine estimated at less than 15 BCM. As an operating rule, it is important to reduce GERD storage to the first filling volume at the end of each hydrological year and to discharge the full annual Blue Nile flows throughout the same hydrological year to reduce the cumulative impact of evaporation and seepage losses and to absorb the flows of the next year's flood.

A comprehensive climate change impacts study on the Blue Nile Basin is needed to reduce the level of uncertainty about the predicted flows, and to assess the GERD impacts on downstream countries in light of climate change impacts.

The conclusion of a detailed binding agreement between Egypt, Sudan and Ethiopia on the first filling and the operating rules and the mechanism for coordination in dam management in the three countries is very important. It is important to include in the detailed agreement, Ethiopia's commitment to limit the use of the GERD reservoir to hydropower purposes as per the Declaration of Principles signed by the three heads of states to ensure water security for the downstream countries. The countries should discuss compensation principles for the

possible negative impact on Egypt's and Sudan's water shares and hydropower generation from the HAD in Egypt and other dams in Sudan pursuant to the provisions of the Declaration of Principles.

Impacts of different operating rules scenarios for the daily GERD discharges should also be studied and linked to the rules of annual GERD discharges. This is important to avoid negative impacts of high daily GERD discharges on Sudanese dams downstream, while ensuring that no negative impacts of low annual GERD discharges will be affecting water availability for Egypt downstream.

References

Abou El-Magd, Islam and Ali, Elham (2012). "Estimation of the evaporative losses from Reservoir Nasser, Egypt, Using Optical Satellite Imagery", National Authority for Remote Sensing and Space Sciences, Suez University, Article in International Journal of Digital Earth (March, 2012).

AbuZeid, K. (2018). "Potential Impacts of the Grand Ethiopian Renaissance Dam on the Nile Water Availability to Egypt and Sudan", (in Arabic), The Official Journal of the Arab Water Council, Pages 38-62, Volume 9, No. 2, December 2018, ISSN 1996-5699, (2018a).

AbuZeid, K. (2018). "Egypt State of the Water Indicators – 2015", Workshop, Cairo, December, (2018b).

AbuZeid, K. (2017). "Potential Impacts of Grand Ethiopian Renaissance Dam (GERD) on Egypt and Sudan", Water Resources Program, Centre for Environment and Development Center for the Arab Region and Europe (CEDARE) (2017a).

AbuZeid, K. (2017). "Potential Impacts of Grand Ethiopian Renaissance Dam on Nile Water Availability for Egypt and Sudan", "Shared Waters in the Arab Region: Potential Transboundary Impacts and Cooperation Opportunities", 4th Arab Water Forum AWC, 27 November 2017, Cairo, Egypt (2017b).

AbuZeid, K., CEDARE and Fayoum University (2016). "Chapter IV: Impacts of the Operation of the GERD", Water Resources Program (Center for Environment and Development for Arab Region and Europe - CEDARE), "Economic Impacts of the GERD on Water, Agriculture and Egypt's National Security", Institute of Research and Strategic Studies on the Nile Basin Countries (Fayoum University) (2016).

AbuZeid, K. (2012). The Watercourse/Blue Water and River Basin/Green Water Approach to Win-Win Solutions in Transboundary River Basin Management." The Official Journal of the Arab Water Council, Pages 1-15, Volume 3, No. 1, July 2012, ISSN 1996-5699. (2012).

Abu-Zeid, Mahmoud (2010). "Arab and African Water in the Twenty First Century". El-Tobgy Foundation for Trading, Printing and Publishing, Cairo (2010).

Bashar, Kamaledin E. and Mustafa, Mohanad O. (2009). "Water Balance Assessment of the Roseires Reservoir", Intermediate Results Dissemination Workshop, UNESCO, Ministry of Irrigation and Water Resources (Sudan), February 5-6, 2009, Addis Ababa, Ethiopia.

Ministry of Water Resources and Irrigation (MWRI) (2004). "Central Directorate for Nile Water Control Yearly Report, 2003-2004", (2004). P. 44.

Said, Rushdi (1993). "Geology, Hydrology and Utilization." The River Nile. Pergamon Press, Oxford, P. 123.

United Nations Economic and Social Commission for Western Asia (ESCWA) (2017). "Chapter 4: Findings for selected shared water basin in the Arab region, 4.1: Nile River Basin", Arab Climate Change Assessment Report – Main Report. Beirut, E/ESCWA/SDPD/2017/RICCAR/Report. (ESCWA, *et al.* 2017). P. 125.

United Nations Economic and Social Commission for Western Asia (ESCWA) (2017). "Chapter 5: Nile River: Blue Nile Headwaters", Arab Climate Change Assessment Report - Technical Annex. Beirut, E/ESCWA/SDPD/2017/RICCAR/Report/Annex. (ESCWA, *et al.* 2017). P.70.

Wale, Abeyou (2008). "Hydrological Balance of Reservoir Tana Upper Blue Nile Basin", Thesis submitted to the International Institute for Geo-Information Science and Earth Observation (ITC), Ethiopia, (April, 2008).