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# Climate Change and Water Resources in Africa

Perspectives and Solutions Towards  
an Imminent Water Crisis

 Springer



Illustration: Photo taken by Khaled AbuZeid

Date: 16 June 2011—Location: Marchison Falls, Nile River, Uganda

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ISBN 978-3-030-61224-5

ISBN 978-3-030-61225-2 (eBook)

<https://doi.org/10.1007/978-3-030-61225-2>

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# Chapter 16

## Potential Transboundary Impacts of the Grand Ethiopian Renaissance Dam Under Climate Change and Variability



Khaled M. AbuZeid

**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), equivalent to about 60% of the natural average flow of the Main Nile at Aswan in Egypt. Egypt depends on Nile River waters as its main source of renewable water, utilizing 55.5 BCM annually as per the 1959 agreement which entitles Sudan to 18.5 BCM per year, making Sudan also highly dependent 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 to generate hydropower. The GERD's reservoir maximum storage capacity is 74 BCM and is projected to start filling in 2020, with full operation planned for 2022. The combined effect of the GERD filling and operation, together with the effect of climate change and variability on the flows of the Blue Nile, calls for careful assessment of the transboundary implications on downstream. This chapter presents an assessment of the transboundary impacts of GERD filling and operation on downstream flows to Sudan and Egypt. Climate variability exacerbates the impacts of the GERD, especially during years of drought. The analysis was based on 105 historical years of Blue Nile flows, simulation of 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, and four different scenarios for annual operation. Modeling shows that climate change effects, if they materialize with more precipitation, may naturally mitigate the negative impacts of the GERD on downstream countries so that they can meet their basic water needs during droughts. In contrast, if climate change effects materialize with less precipitation this will result in the reduction of flows of the Blue Nile, and the GERD's transboundary negative impacts will be exacerbated.

**Keywords** GERD · Impacts · Nile river · Climate · Transboundary · Renaissance dam · Blue Nile · Egypt · Sudan · Ethiopia · High Aswan Dam

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# 1 The Nile River Basin and the Blue Nile Basin Climate Variability

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 (AbuZeid 2016). Ethiopia, with the 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 created the dependence of Egypt and Northern Sudan 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 expected that upstream countries such as Ethiopia rely on “rainwater” in the Nile Basin, whereas downstream countries such as Egypt and Sudan rely on “running water” from 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 use only about 4.6% of the total rainfall in the 11 countries of the Nile Basin, which is about 1660 BCM per year on average. The rainfall in the Nile countries, including other basins, is about 7000 BCM annually on average, with annual variation corresponding to temporal climate variability. Figure 1 shows the

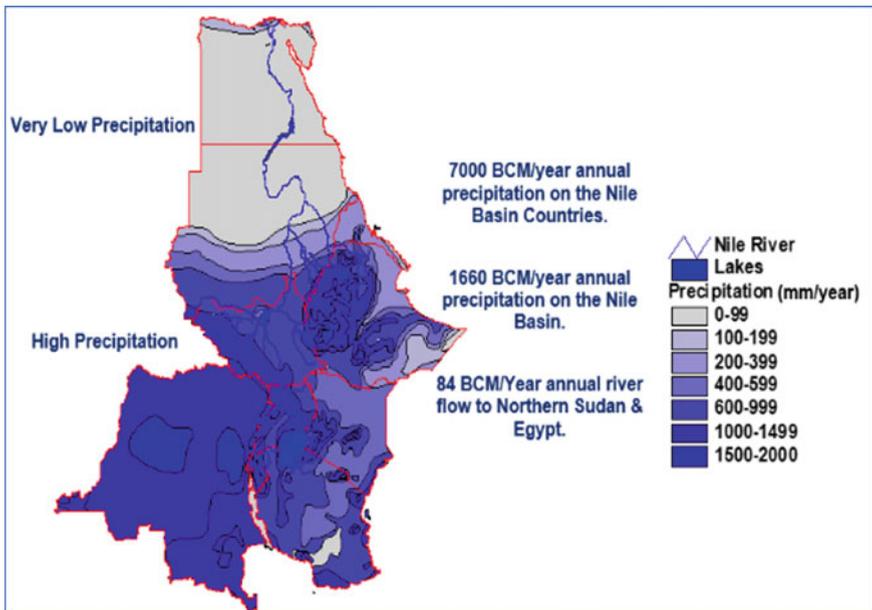


Fig. 1 Distribution of rainfall on the Nile Basin countries (AbuZeid 2012)

distribution of rainfall on the Nile Basin countries, reflecting the wide range of spatial geographical climate variability.

According to the 1959 agreement, Sudan's annual share from the Nile is 18.5 BCM. Egypt's annual share is 55.5 BCM, and is governed by the 1959 agreement and confirmed by historical uses for decades. This share is not enough to meet Egypt's increasing water needs. In 2015, Egypt imported agricultural food products that would have required about 50 BCM of (virtual) water to grow (AbuZeid 2018). Egypt is the only country among those in the Nile Basin that is forced to reuse wastewater and agricultural drainage to meet its water demand. It has also desalinated seawater for decades to fill the water gap on the coasts of the Red Sea and recently in cities on the Mediterranean Sea. Satellite images confirm Ethiopia's use of the Blue Nile Basin water in agriculture, industry, and urban development, but no data is published showing the exact abstractions or water uses in the Blue Nile Basin in Ethiopia. However, Ethiopia's agriculture is more dependent on rainfall. The Blue Nile is the main tributary of the Nile River, and has the largest flow volume among all major tributaries, discharging about 50 BCM/year on average. The effect of annual climate variability on the Blue Nile can be inferred from the recorded flows from 1911 to 2015, with a range from 20.69 BCM/year in 1913 to 69.85 BCM/year in 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.

## 2 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 project was about 65% complete by November 2017. Figure 2 shows the progress of construction on the GERD and the auxiliary Saddle Dam as of 2017.

GERD has become controversial because of its potential impacts on downstream countries, Egypt and Sudan. In an attempt to assess the impact of the GERD on Egypt and Sudan during filling and 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 (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 Egypt, Ethiopia, and Sudan in March 2015, stipulates that the three countries will agree on “the first filling rules, the annual operation rules and will establish a mechanism to coordinate the management of dams and reservoirs in the three countries.” It is therefore important to study the potential impacts of the GERD on the downstream countries of Sudan and Egypt, so that determinations about filling and operating rules can be made based on the results. A consortium of two consulting firms was hired by the three countries to conduct formal impact assessment studies.

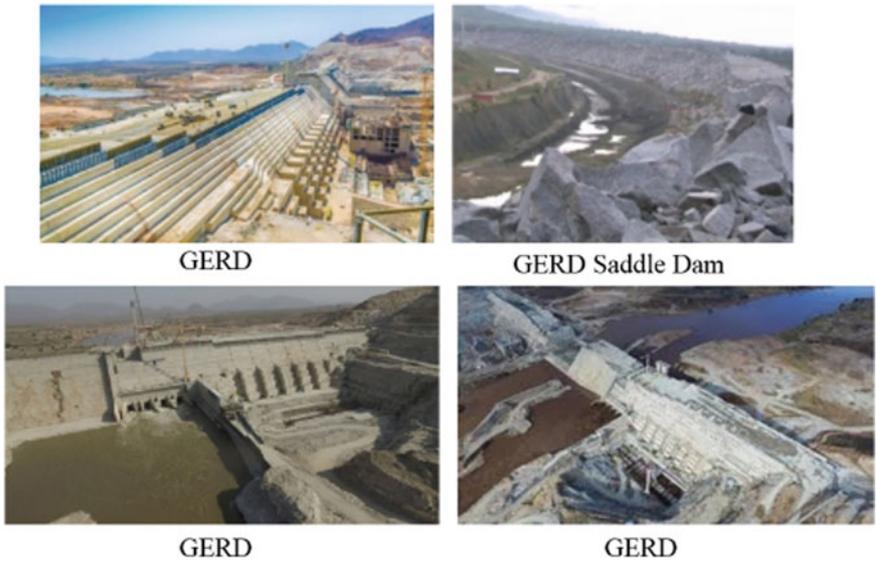


Fig. 2 Progress of construction in the GERD and the auxiliary Saddle Dam as of 2017

However, progress on the studies has been delayed due to disagreements among countries.

Figure 3 shows the High Aswan Dam (HAD) that lies downstream of the GERD in Egypt; HAD is the control structure that regulates the release of flows for Egypt's water uses as per the 1959 agreement with Sudan which allocates 55.5 BCM/year for Egypt and 18.5 BCM/year for Sudan.



Fig. 3 High Aswan Dam (HAD) (Egypt)

### 3 GERD Impact Assessment Methodology, Scenarios, and Assumptions

The study of the impacts of the first filling and operation of the GERD is based on simulating more than 100 possible scenarios (AbuZeid 2017b). The amount of the first seepage losses, annual seepage, and annual evaporation from the GERD 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, 25, and 62 BCM over a period of 6 years, 10 years, and in some cases, 4 or 5 years. The study is based on simulating the historical series (1911–2015) of Blue Nile flows on which GERD is being built in Ethiopia (Abu-Zeid 2010; Said 1993). Different water levels in the High Aswan Dam (HAD) reservoir of 150 meters (m), 160, 165, 170, and 175 m (above mean sea level) were used as simulations for the HAD level 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 modeled into the future when the GERD is in place. The impact of the GERD on the flows of the Blue Nile downstream and the water levels and storage volumes of the HAD reservoir was predicted by the model, taking into account the other Nile tributaries flows and Egypt's and Sudan's shares of the Nile water. The results were compared to the baseline scenario (without GERD). The number of years of water deficit for Egypt and Sudan, and the volume of the deficits were assessed for every scenario. Since there is no agreement yet on the operating rules of the GERD, assumptions for operation scenarios were made based on lowering the reservoir levels of GERD by the end of the hydrological year back to different scenarios for the first filling volume of 15, 25, and 62 BCM.

The “first filling” is defined as filling up the dead storage volume in addition to a safety height of about 20 m above the level of the main turbines, to 590 m above mean sea level (amsl), which is equivalent to total storage of around 15 BCM. The relationship between the water level in the GERD reservoir and the water surface area, and the storage volume in the GERD reservoir is depicted in Fig. 4.

The “first seepage” and “annual seepage” from GERD were assumed as per the “average scenario” in the charts given in Figs. 5 and 6.

According to Wale (2008), the evaporation rate from Lake Tana in Ethiopia, the surface water level of which is 1786 m (amsl), is about 4.63 mm/day. According to Bashar and Mustafa (2009), the evaporation rate from the Roseires Dam Reservoir in Sudan, the water level of which is 480 m (amsl), has an average evaporation rate of about 6.62 mm/day. As the GERD highest water level is about 640 m (amsl), by interpolation the evaporation rate of the GERD reservoir may be estimated to be 6.38 mm/day. This estimated evaporation rate is reflected by the “interpolation scenario” for GERD “annual evaporation” as shown in Fig. 7. The assessment in this study uses the “average” scenario.

The relationship among the water level in the HAD reservoir, the water surface area, and the storage volume is presented in Fig. 8.

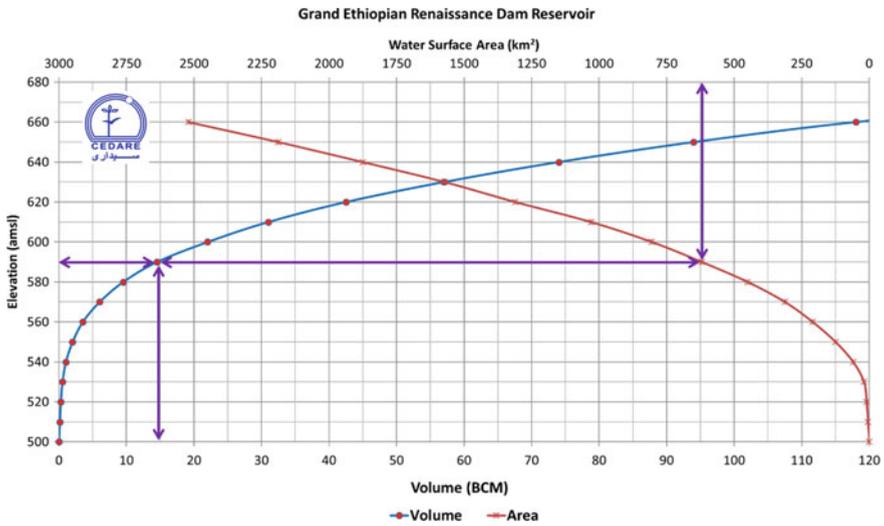


Fig. 4 The relationship between the water elevation, surface area, and volume in the GERD reservoir

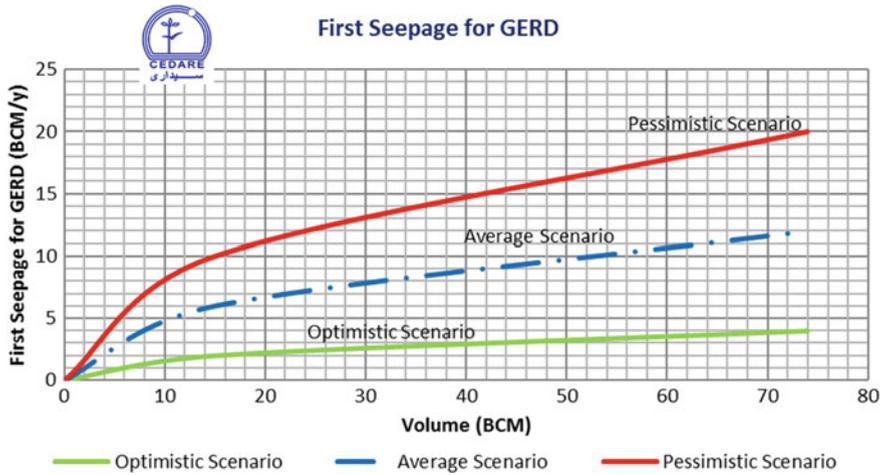


Fig. 5 The “first seepage” scenarios from GERD related to the storage volume

According to Abou El-Magd and 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 Fig. 8 for calculating the evaporation and seepage losses from the HAD Reservoir, assuming seepage losses of about 2 BCM/year at the maximum water level. Assumptions for evaporation and seepage losses from the HAD reservoir are shown in Fig. 9.

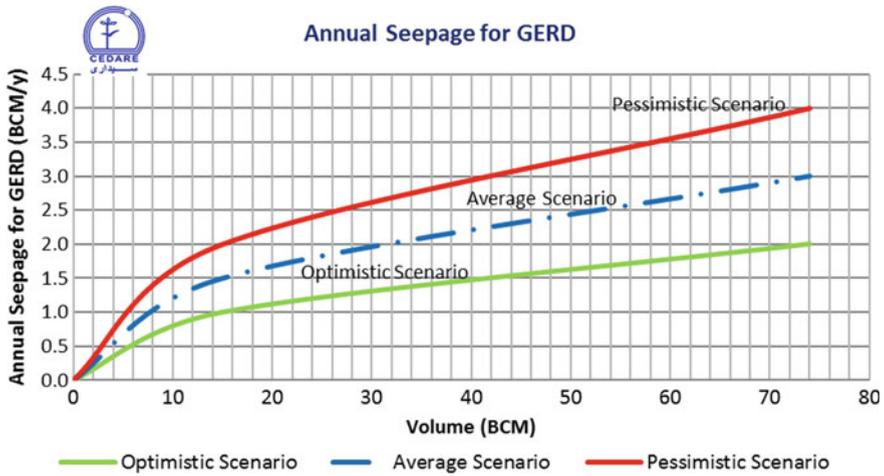


Fig. 6 The “annual seepage” scenarios from GERD related to the storage volume

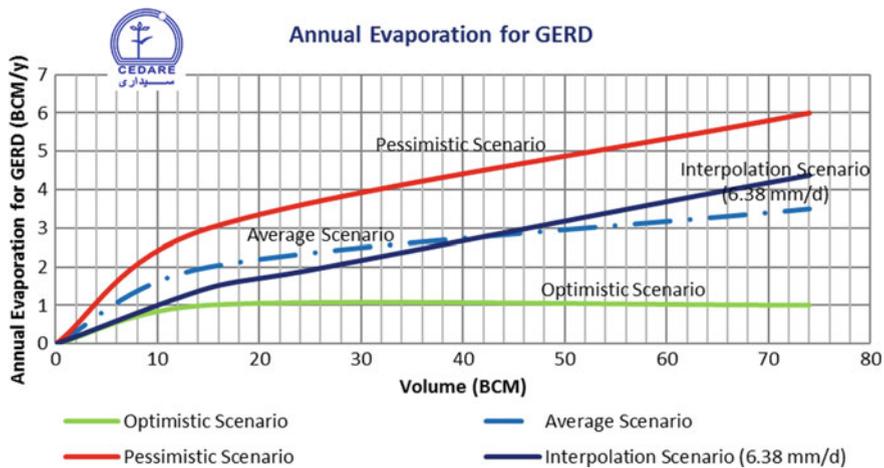


Fig. 7 GERD “annual evaporation” scenarios related to storage volume

GERD operating rules are based on Blue Nile flow storage during the high flow period (July–October), which represents about 80% of 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 flow of the White Nile River was considered to be 28.5 BCM/year at Malakal, the annual average flow of the Atbara River to be 12 BCM/year, and that of the Rahad and Dinder Rivers at Khartoum to be 4 BCM/year. The average annual losses from the Roseires and Sennar Dam Reservoirs were estimated at 0.9 BCM/year. The average annual losses were estimated to be 1.0 BCM/year from the

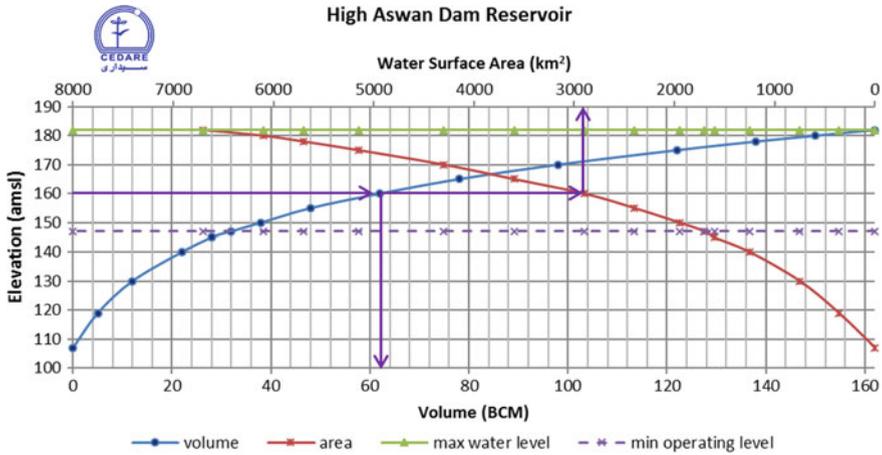


Fig. 8 Relationship between water elevation, surface area, and volume in the HAD reservoir

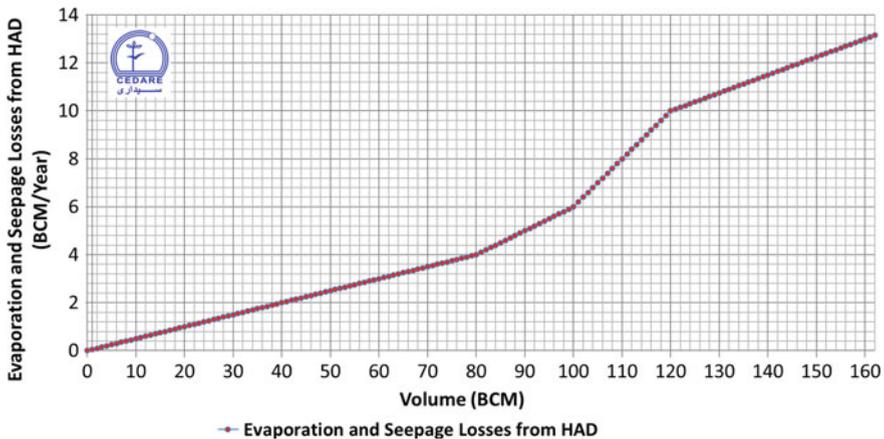


Fig. 9 Relationship between volume and evaporation and seepage losses from the HAD reservoir

Atbara, Tekizi, and Khashm El-Girba Dam Reservoirs, 2.5 BCM/year from Jebel El-Awliaa Dam Reservoir, 1.8 BCM/year from the Marwi Dam Reservoir, and 3.3 BCM/year from the upstream Nile River reaches to Aswan (MWRI 2004).

Projections for Blue Nile 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 (historical 10-year average). It was assumed that the flow volumes of the Blue Nile between 1911 and 2015 will be repeated in the same order for the next 105 years starting as soon as the GERD filling starts.



GERD reservoir and the smaller the impact on the flows downstream to Egypt and Sudan. Thus, the best case scenario is when the GERD reservoir returns to 15 BCM at a level of about 590 m at the end of the hydrological year. In reality, the level may need to drop to 7 or 3 BCM in very dry years, however, this was not simulated in this study. When the level is this low, it is insufficient to operate any of the top 14 turbines, leaving just the two lower turbines operable. Figure 11 shows the effect of the remaining storage volume at the end of the hydrological year during operation on the number of deficit years and in providing the allocated shares to Egypt and Sudan during the 105-year period used for simulating the filling and operation of the GERD. Scenarios include different sizes for the minimum operating volumes of (15, 25, 62, and 74 BCM) at the end of the hydrological year, during the time series modeled. Scenarios also include three different 10-year averages of Blue Nile during the first filling before annual operation.

Figure 12 shows a set of possible scenarios for the HAD reservoir end-of-year storage for the projected 105 years following the completion of the GERD, starting with 10-year average flows of 38 BCM during “first filling,” compared to the baseline scenario without the presence of the GERD. It is clear from all the scenarios presented that HAD storage falls under the dead storage level of 31 BCM (i.e., below the level at which turbines can operate) due to the expected cumulative effect of evaporation losses and seepage in the GERD reservoir, which will be evident in years of low Blue Nile flows.

Figure 13 shows a set of possible scenarios for the HAD reservoir end-of-year storage in the 105 years following the completion of the GERD starting with 10-year average flows of 45 BCM during “first filling,” compared to the baseline scenario without the presence of the GERD. It is clear from all the scenarios presented that HAD storage falls under the dead storage level of 31 BCM (i.e., below the level at which turbines can operate) due to the expected cumulative effect of evaporation

Operating after first filling period of different volumes and keeping this storage as the minimum during operation	Average flows for Blue Nile in the first 10 years of filling and operation (m <sup>3</sup> / year)	Water level in front of the HAD at the beginning of the time series 150 m			Water level in front of the HAD at the beginning of the time series 160 m			Water level in front of the HAD at the beginning of the time series 165 m			Water level in front of the HAD at the beginning of the time series 170 m			Water level in front of the HAD at the beginning of the time series 175 m			
		Filling volume scenarios, remaining minimum range during operation BCM			Filling volume scenarios, remaining minimum range during operation BCM			Filling volume scenarios, remaining minimum range during operation BCM			Filling volume scenarios, remaining minimum range during operation BCM			Filling volume scenarios, remaining minimum range during operation BCM			
		15	25	74	15	25	74	15	25	74	15	25	74	15	25	62	74
		Deficit years in providing Egypt and Sudan shares			Deficit years in providing Egypt and Sudan shares			Deficit years in providing Egypt and Sudan shares			Deficit years in providing Egypt and Sudan shares			Deficit years in providing Egypt and Sudan shares			
Filling Period in 10 Years	50 45 38	20 18 19	22 20 20	37 28 24	15 16 16	16 18 17	34 24 22	15 15 15	16 17 16	30 23 21	15 14 14	16 17 15	21 23 20	15 14 12	16 16 15	21 16 15	21 22 19
Filling Period in 6 Years	50 45 38	21 19 19	23 21 20	29 29 24	15 16 16	18 23 18	28 26 23	15 15 15	16 17 18	26 25 22	15 14 14	16 16 16	25 24 21	15 12 12	16 16 15	21 16 20	21 23 20
Filling Period in 5 Years	50 45 38																23
Filling Period in 4 Years	50 45 38																21

Fig. 11 Scenarios for the number of deficit years during GERD operation

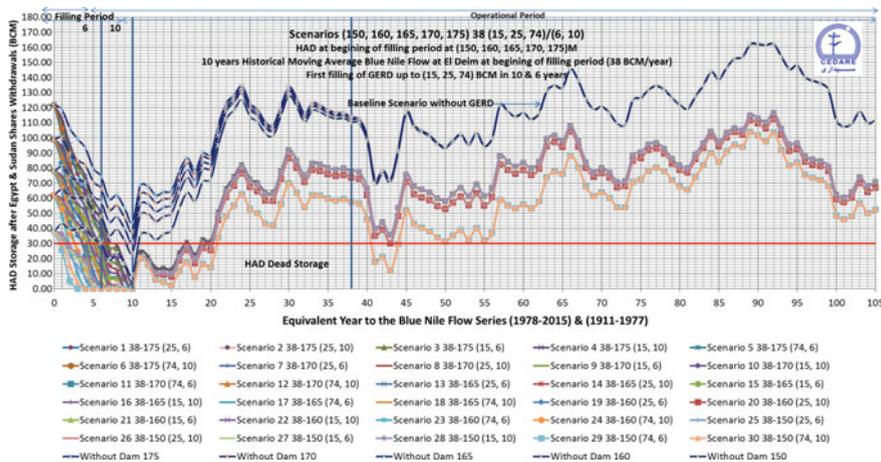


Fig. 12 Scenarios: (150, 160, 165, 170, 175) 38 (15, 25, 74)/(6, 10)

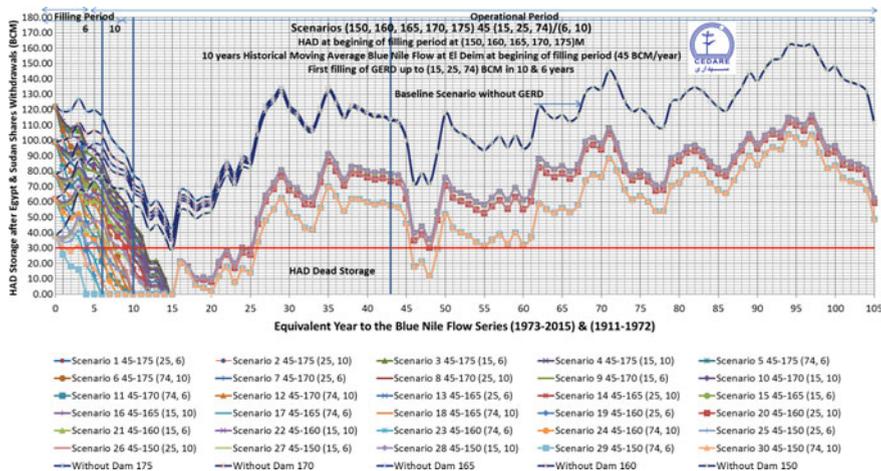


Fig. 13 Scenarios: (150, 160, 165, 170, 175) 45 (15, 25, 74)/(6, 10)

losses and seepage in the GERD reservoir, which will be evident in years of low Blue Nile flows.

Figure 14 shows a set of possible scenarios for the HAD reservoir end-of-year storage in the 105 years following the completion of the GERD, starting with 10-year average flows of 50 BCM during “first filling,” compared to the baseline scenario without the presence of the GERD. It is clear from all the scenarios presented that HAD storage falls under the dead storage level of 31 BCM (i.e., below the level at which turbines can operate) due to the expected cumulative effect of evaporation

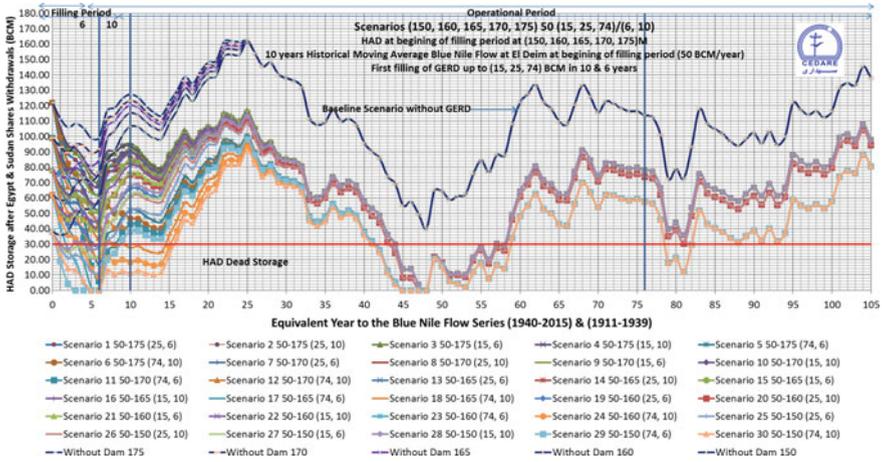


Fig. 14 Scenarios: (150, 160, 165, 170, 175) 50 (15, 25, 74)/(6,10)

losses and seepage in the GERD reservoir, which will be evident in years of low Blue Nile flows.

The graphs below analyze separate scenarios of potential HAD storage at the end of the hydrological year in the presence of the GERD compared to the baseline scenario without the GERD. Some unlikely scenarios were excluded, such as those scenarios when the Blue Nile average mean of 10 consecutive years is low and the beginning of this period coincides with the lowest level in the HAD reservoir, or when the GERD is operating at a minimum storage of 74 BCM.

### 5 GERD Operation After Filling During a Low 10-Year Average Flow (38 BCM/Year)

Figure 15 assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 38 BCM/year (similar to the period from 1978 to 1987), which was the lowest 10-year historic average, coinciding with a HAD reservoir level at the beginning of the series of about 165 m (equivalent to HAD storage of 78 BCM). This scenario assumes annual operation at 15 BCM minimum storage. Deficit years where the Blue Nile flows through GERD will be short of meeting the shares of Egypt and Sudan reached about 15 years during the first 20 years of the series of 105 years of the simulated historical flows used.

There will be a deficit in the shares of Egypt and Sudan to avoid the falling of the HAD reservoir levels below the dead storage level.

Figure 16 shows an annual deficit ranging from 2.5 BCM to 3 BCM for both Egypt and Sudan for a period of 10 years, with a total deficit during the first 10 years of about 56 BCM.

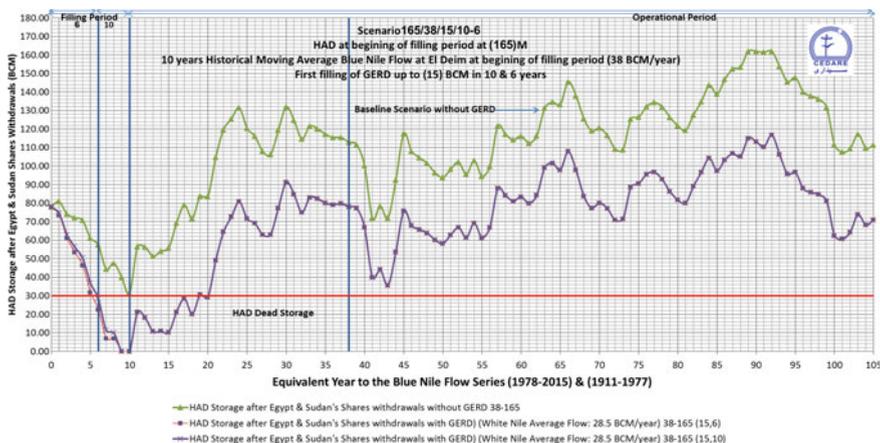


Fig. 15 Scenarios: (165) 38 (15)/(6,10)

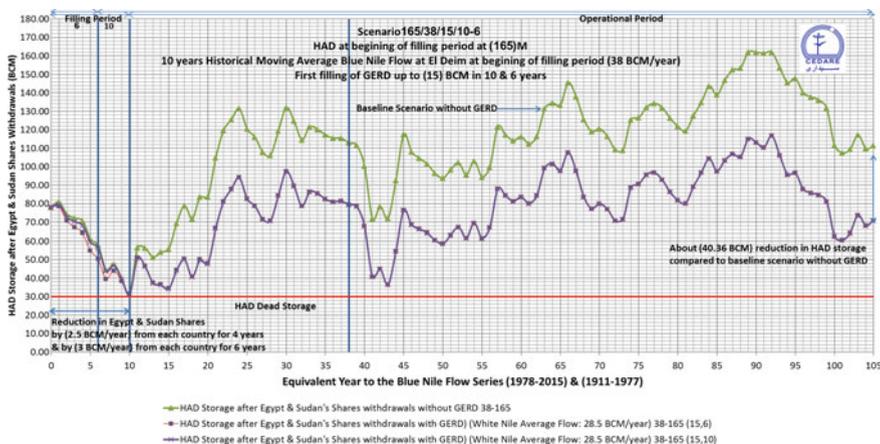


Fig. 16 Scenarios: (165) 38 (15)/(6,10) with deficit in the shares of Egypt and Sudan

Figure 17 assumes a series of flows at the beginning of the filling period of 6 years with a 10-year annual average equal to 38 BCM/year (similar to the period from 1978 to 1987), which was the lowest 10-year historical average, and coinciding with a HAD reservoir level at the beginning of this series at about 170 m (equivalent to HAD storage of about 99 BCM). This scenario assumes the annual operation at 25 BCM minimum storage. Deficit years where Nile water shares of Egypt and Sudan cannot be met reached about 16 years during the first 20 years of the series of 105 years of the simulated historical flows used.

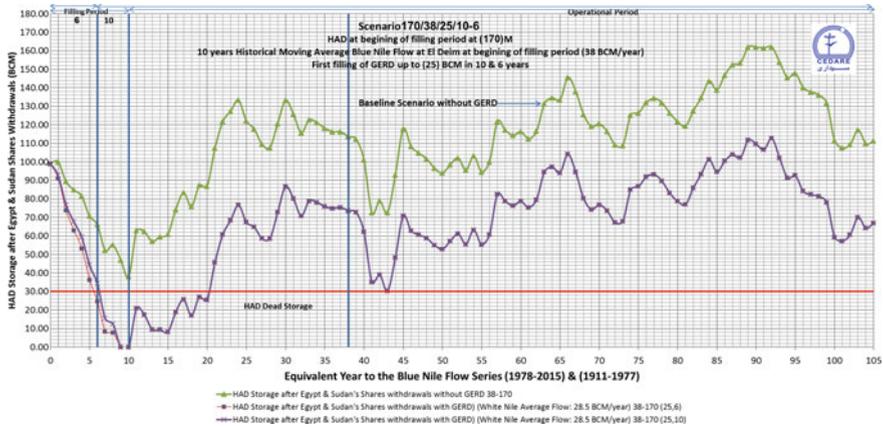


Fig. 17 Scenarios: (170) 38 (25)/(6,10)

Figure 18 shows an annual deficit ranging from 2.5 BCM to 3 BCM for each of Egypt and Sudan for a period of 10 years, with a total deficit during the first 10 years of about 57 BCM for both countries.

Figure 19 assumes a series of flows at the beginning of the filling period of 6 years with a 10-year annual average equal to 38 BCM/year (similar to the period from 1978 to 1987), which was the lowest 10-year historical average, 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 operation at 62 BCM minimum storage. Deficit years where the Blue Nile Flows downstream GERD cannot meet the shares of Egypt and Sudan, reached about 20 years during the first

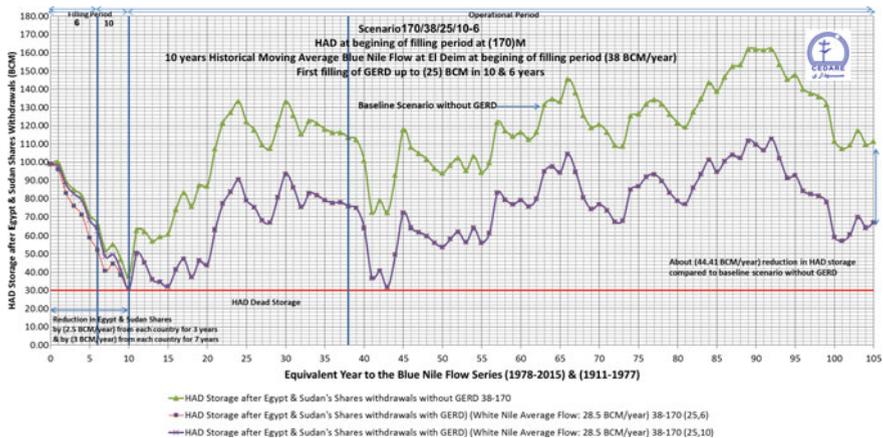


Fig. 18 Scenarios: (170) 38 (25)/(6,10) with deficit in the shares of Egypt and Sudan

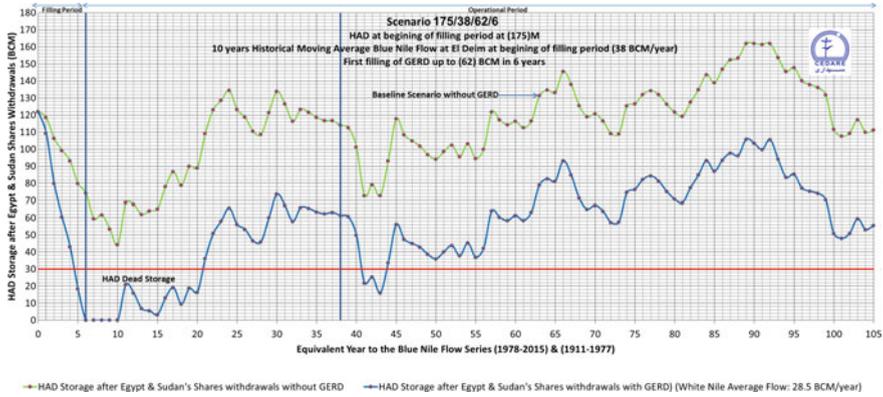


Fig. 19 Scenario: (175) 38 (62)/(6)

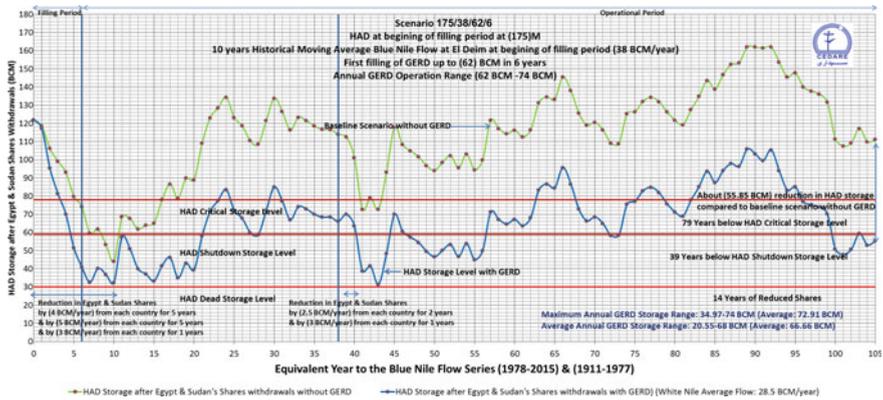


Fig. 20 Scenario: (175) 38 (62)/(6) with deficit in the shares of Egypt and Sudan

20 years and again after 40 years of the series of 105 years of the simulated historical flows used.

Figure 20 shows an annual deficit ranging from 2.5 BCM to 5 BCM for each of Egypt and Sudan for a period of 11 years, at the beginning of the series and for 3 years after 38 years with a total deficit of about 112 BCM for both countries.

## 6 GERD Operation After Filling During a Moderate 10-Year Average Flow (45 BCM/Year)

Figure 21 assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 45 BCM/year (similar to the period from 1973 to 1982),

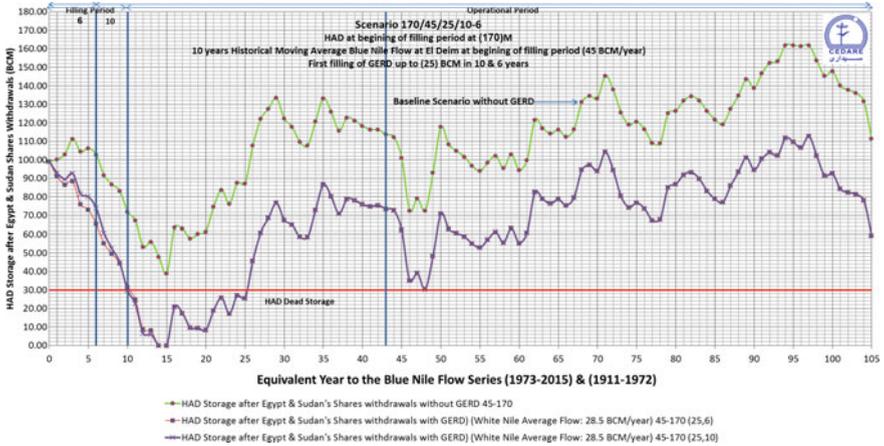


Fig. 21 Scenarios: (170) 45 (25)/(6,10)

which was a moderate 10-year average flow, and coinciding with a HAD reservoir level at the beginning of this series of about 170 m (equivalent to HAD storage of about 99 BCM). This scenario assumes the annual operation at 25 BCM minimum storage. Deficit years where the Blue Nile flows through GERD will not be able to satisfy the shares of Egypt and Sudan, reached about 17 years during the first 25 years and after 47 years of the series of 105 years of the simulated historical flows used.

Figure 22 shows an annual deficit of about 2.5 BCM for each of Egypt and Sudan for a period of 12 years, with a total deficit during the first 14 years of about 60 BCM for both countries.

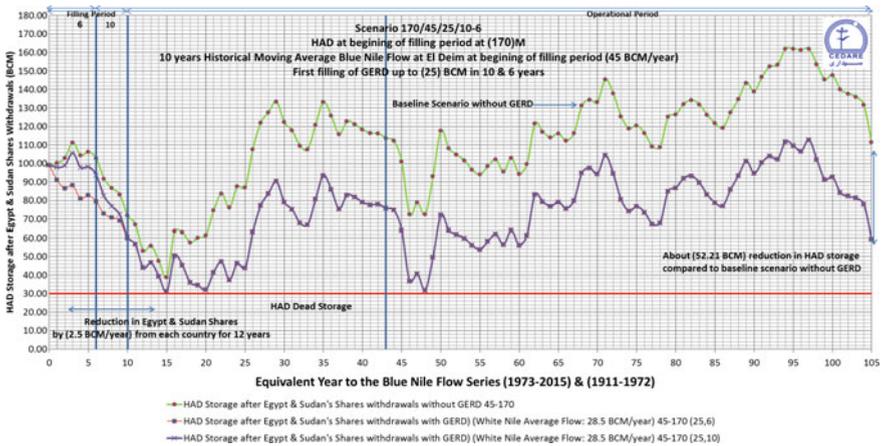


Fig. 22 Scenarios: (170) 45 (25)/(6,10) with deficit in the shares of Egypt and Sudan

Figure 23 assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 45 BCM/year (similar to that which occurred in the period from 1973 to 1982), which was a moderate 10-year historical average, 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 operation at 15 BCM minimum storage. Deficit years of inability of Blue Nile flows through GERD to meet the shares of Egypt and Sudan reached about 14 years during the first 17 years of the series of 105 years of the simulated historical flows used.

Figure 23 also shows an annual deficit of about 2.5 BCM for each of Egypt and Sudan for a period of 8 years, with a total deficit during the first 17 years of about 40 BCM for both countries.

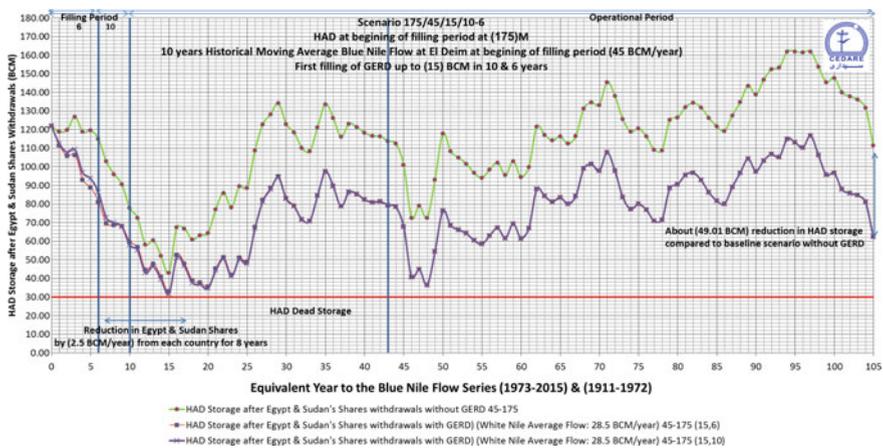


Fig. 23 Scenarios: (175) 45 (15)/(6,10) with deficit in the shares of Egypt and Sudan

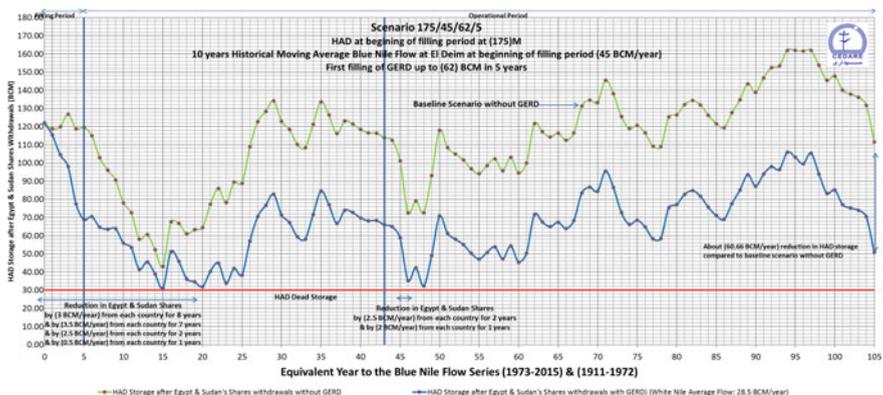


Fig. 24 Scenario: (175) 45 (62)/(5) with deficit in the shares of Egypt and Sudan

Figure 24 assumes a series of flows at the beginning of the filling period with a 10-year annual average equal to 45 BCM/year (similar to the period from 1973 to 1982), which was a moderate 10-year historical average, 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 annual operation at 62 BCM minimum storage. Deficit years where the Blue Nile flows through GERD will not be able to meet the shares of Egypt and Sudan reached about 23 years during the first 20 years and after 42 years of the series of 105 years of the simulated historical flows used.

Figure 24 also shows an annual deficit ranging from 0.5 BCM to 3 BCM for each of Egypt and Sudan for a period of 18 years at the beginning of the series and a period of 3 years after 42 years, with a total deficit of about 122 BCM for both countries.

### 7 GERD Operation After Filling During a 10-Year Average Flow (50 BCM/Year)

Figure 25 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 the period from 1940 to 1949), which is an average 10-year average flow, and coinciding with a HAD reservoir level at the beginning of this series at about 160 m (equivalent to HAD storage of 62 BCM). This scenario assumes an annual operation at 15 BCM minimum storage. Deficit years where the Blue Nile flows through GERD will not be able to meet the shares of Egypt and Sudan reached about 10 years after 38 years of the series of 105 years of the simulated historical flows used.

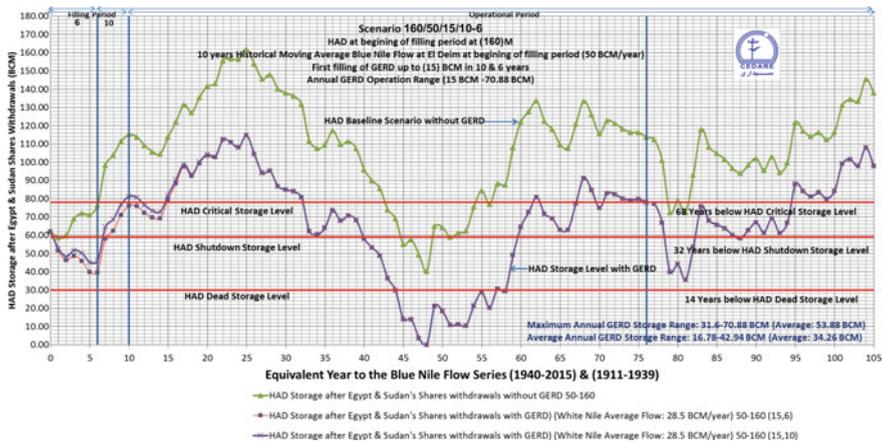
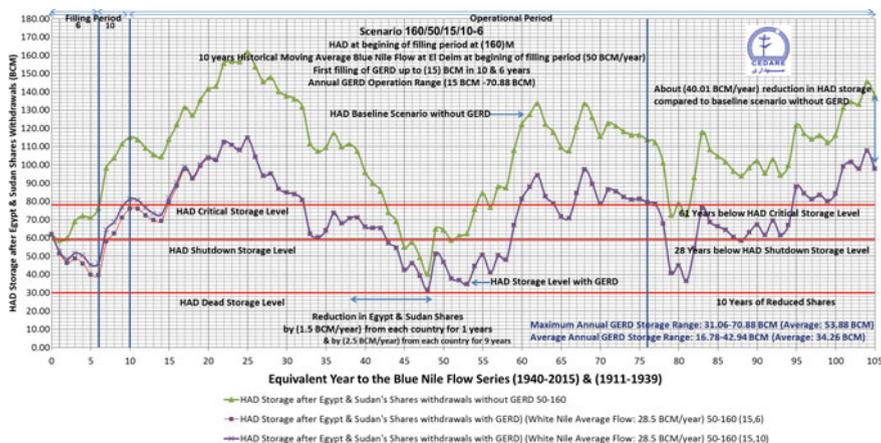


Fig. 25 Scenarios: (160) 50 (15)/(6,10)



**Fig. 26** Scenarios: (160) 50 (15)/(6,10) with deficit in the shares of Egypt and Sudan

Figure 26 shows an annual deficit ranging from 1.5 to 2.5 BCM for each of Egypt and Sudan for a period of 10 years, with a total deficit after 38 years of about 48 BCM for both countries.

Figure 26 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 the period from 1940 to 1949), which is an average 10-year average flow, and coinciding with a HAD reservoir level at the beginning of this series of about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes annual operation at 25 BCM minimum storage. Deficit years where the Blue Nile flows through GERD will not be able to meet the shares of Egypt and Sudan reached about 16 years after 36 years of the series of 105 years of the simulated historical flows used.

Figure 27 shows an annual deficit of about 2.5 BCM for each of Egypt and Sudan for a period of 12 years, with a total deficit after 36 years of about 60 BCM for both countries.

Figure 28 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 the period from 1940 to 1949), which is an average 10-year average flow, and coinciding with a HAD reservoir level at the beginning of this series of about 175 m (equivalent to HAD storage of 122 BCM). This scenario assumes the annual operation at 62 BCM minimum storage. Deficit years where the Blue Nile flows through GERD will not be able to meet the shares of Egypt and Sudan reached about 21 years at different periods of the series of 105 years of the simulated historical flows used.

Figure 28 shows an annual deficit ranging from 0.5 BCM to 3 BCM for each of Egypt and Sudan for a period of 29 years, with a total deficit in the different period of the series about 124 BCM for both countries.

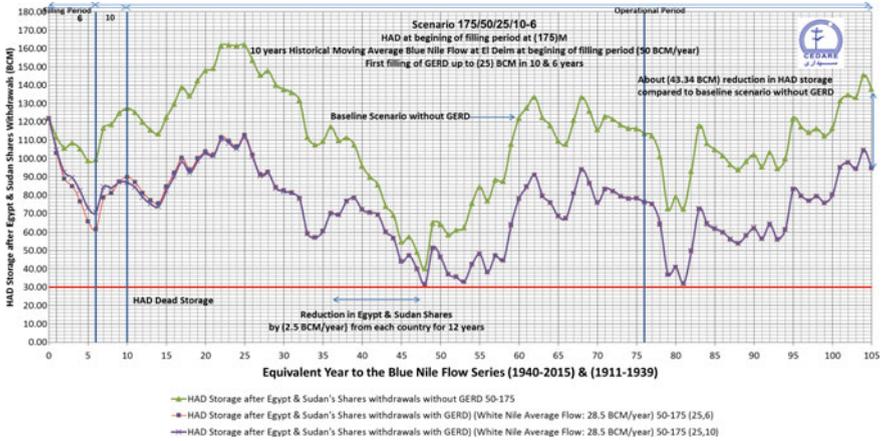


Fig. 27 Scenarios: (175) 50 (25)/(6,10) with deficit in the shares of Egypt and Sudan

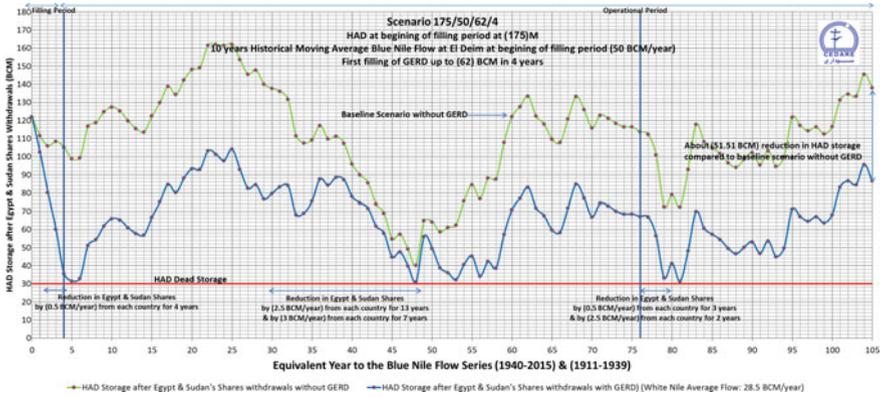


Fig. 28 Scenario: (175) 50 (62)/(4) with deficit in the shares of Egypt and Sudan

## 8 Deficit Years and Volumes for Selected GERD Filling and Operation Scenarios

Figure 29 shows water-deficit years and volumes of deficit for the selected scenarios for Egypt and Sudan applied to the simulated historical series of flows used during the “operating period” after “first filling” of an amount of 15 BCM and keeping this storage as a minimum operating level.



Operating after first filling period of 62 BCM and keeping this storage as the minimum during operation	Average flows for Blue Nile in the first 10 years of filling and operation (m <sup>3</sup> / year)	Water level in front of the HAD at the beginning of time series at 175 m								Total Deficit Volume per country
		Withdrawals by Egypt and Sudan								
		55.5	55	53.5	53	52.5	52	51.5	50.5	
		18.5	18	16.5	16	15.5	15	14.5	13.5	
		Deficiency Volume (BCM/year/each country)								
		Variable	0.5	2	2.5	3	3.5	4	5	
Deficiency Years										
Filling Period in 4 Years	50	21	7		15	7			62	
Filling Period in 5 Years	45	23	1	1	4	8	7		61	
Filling Period in 6 Years	38	20			2	2		5	5	56

Fig. 31 Deficit years and volumes for Egypt and Sudan while GERD is operating at 62 BCM end of year

### 9 GERD Impacts on HAD Hydropower

The impact on a shortage of hydropower generated from the HAD is evident, unless parties agree to discharge the entire flow of the Blue Nile in the same months it arrives, without distributing the flows throughout the year. However, uniform hydropower production throughout the year from GERD leads to a decrease in average water levels in the HAD, even when the entire flow is discharged annually after the filling period. The HAD’s hydropower may decrease by 24–40% due to the GERD. Hydropower of the HAD does not represent a large proportion of the generated power at the national level in Egypt, but it does account for about one-third of the hydropower to be generated by the GERD and contributes to meeting the demands of two or more governorates in Upper Egypt.

Figure 32 shows a decrease 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 of 25 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 11.5 m in the average water level in the HAD. Minimum reductions are also shown in Fig. 32.

Figure 33 shows a decrease 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 of 15 BCM and ensuring that GERD levels return to that level by the end of the hydrological year. This operating rule at 15 BCM has the least impact on the hydropower of HAD downstream in Egypt. These scenarios lead to a maximum reduction in the average reservoir storage of HAD of about 43

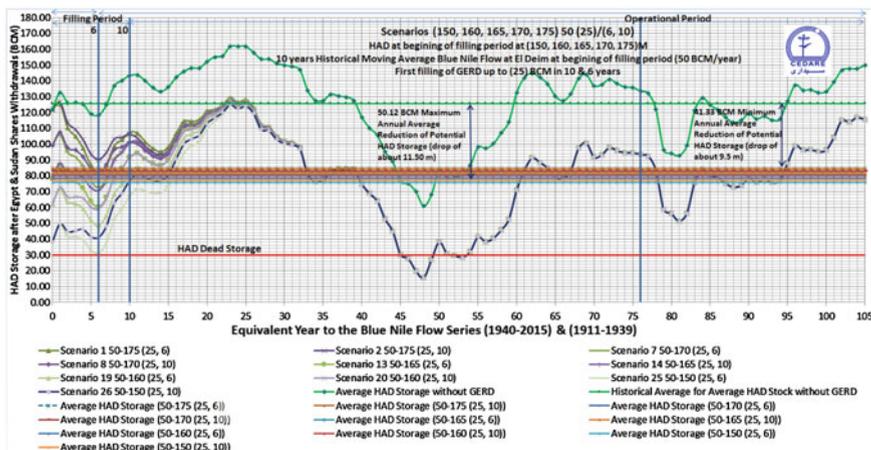


Fig. 32 HAD average content/level scenarios: (150, 160, 165, 170, 175) 50 (25)/(6,10)

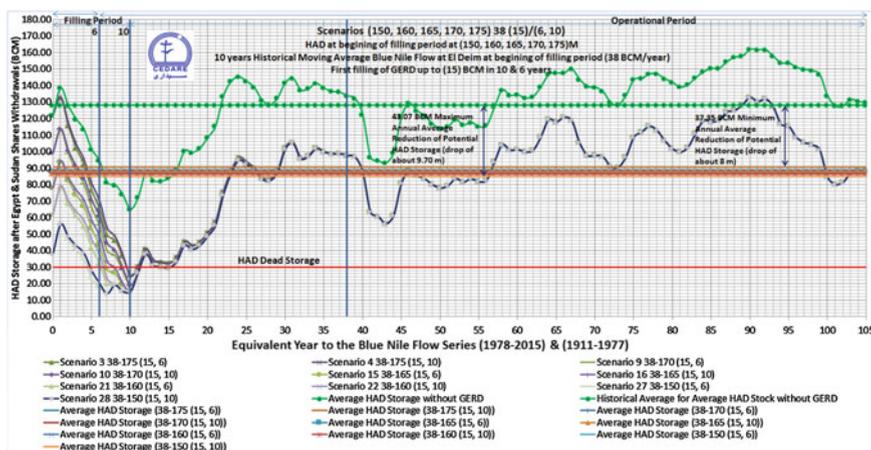


Fig. 33 HAD average content/level scenarios: (150, 160, 165, 170, 175) 38 (15)/(6, 10)

BCM, and a maximum drop of about 9.7 m in the average water level in the HAD. Minimum reductions are also shown in Fig. 33.

Figure 34 shows a decrease 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 of 15 BCM and ensuring that GERD levels return to that level by the end of the hydrological year. This operating rule at 15 BCM has the least impact on the hydropower of downstream countries. These scenarios lead to a reduction in the average reservoir storage of HAD of about 30 to 37 BCM, and a drop of about 6.5 to 8 m in the average water level in the HAD.

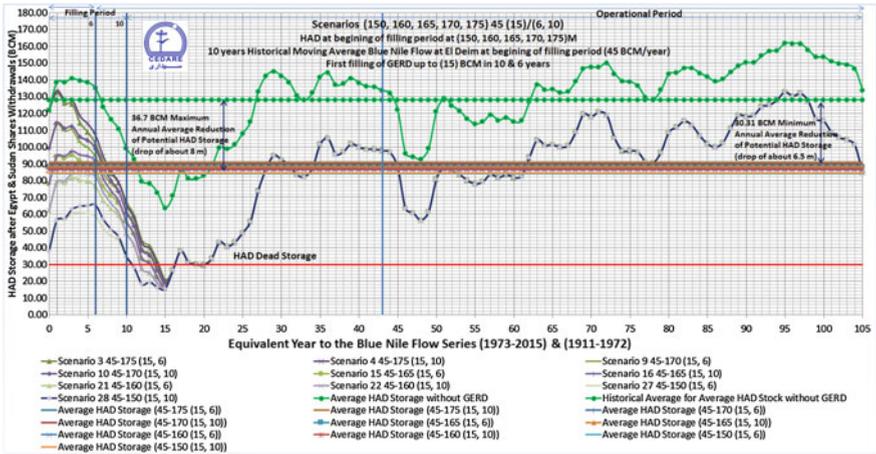


Fig. 34 HAD average content/level scenarios: (150, 160, 165, 170, 175) 45 (15)/(6,10)

Figure 35 shows a reduction in the hydropower generation head ranging from 24 to 40%, which will have a similar effect on the decrease in hydropower generated from the HAD due to the presence of the GERD as a consequence of a decrease in the average HAD level, which corresponds to reductions in average annual storage ranging from 30 to 50 BCM.

	Average flows in the first 10 years of filling and operation	The minimum reduction in average HAD storage (BCM)	The maximum reduction in the average HAD storage (BCM)	The minimum reduction in the average level in the HAD (m)	The maximum reduction in the average level in the HAD (m)	The minimum percentage reduction in hydropower generation head	The maximum percentage reduction in hydropower generation head
Operating at 15 BCM	50	37.28	45.17	8.30	10.30	29%	36%
	45	30.31	36.70	6.50	8.00	24%	29%
	38	37.35	43.07	8.00	9.70	27%	33%
Operating at 25 BCM	50	41.33	50.12	9.50	11.50	33%	40%
	45	34.30	40.89	7.00	9.00	25%	33%
	38	41.69	46.82	9.20	10.20	32%	35%

Fig. 35 Reduction estimates in HAD hydropower generation & reflected by reduced volumes and levels

## 10 Potential Climate Change Impacts on the Blue Nile Flows

According to ESCWA (2017a, b), in the Blue Nile Basin, the change in mean temperature for Representative Concentration Pathway (RCP) 4.5 shows an increase of 1.5 °C at mid-century and 1.8 °C at end century. For RCP 8.5, temperatures increase by 2 °C for mid-century and 3.6 °C at end century. At the seasonal level, the highest increase in temperature is shown to occur in winter with an increase of as much as 3.9 °C by the end of the century for RCP 8.5. Precipitation results for RCP 4.5 projected a change of -6 and -5% at mid- and end centuries, respectively. For RCP 8.5, precipitation change is -3% for mid-century and -5% by end century, reaching the greatest reduction in winter, with a 7% decrease.

The headwaters of the Blue Nile in the Ethiopian Highlands show broad variation among individual ensemble members for runoff in both models (HYPER and VIC); no conclusive trend can be perceived. The mean values from discharge changes show a decrease over time, but, given the broad ranges, this trend cannot be considered conclusive. For instance, the change in mean discharge for end century is -8% for RCP 8.5, but values range from -68 to 86%, as shown in Fig. 36.

The direction of change of flows of the Blue Nile has inverse impacts when reconciled with GERD impacts as described above. If the direction of the change is positive (increased flow), the result can be a reduced impact of GERD on Egypt and Sudan. But if there is a decrease in Blue Nile flows (as suggested by the direction of the mean discharge of -8%), GERD impacts on Egypt and Sudan are exacerbated.

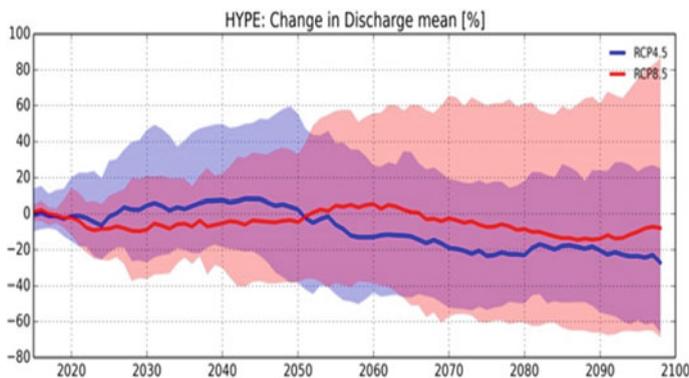


Fig. 36 HYPER: change in Blue Nile discharge mean (%), (ESCWA 2017a, b)

## 11 Conclusion

There is a failure to fulfill the shares of Egypt and Sudan in almost 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 the volume of dead storage (storage up to the highest level of the turbines), the first filling volume, and the average annual storage volume, which affects the volume of evaporation losses and seepage. The cumulative effects of these losses have a great impact on the volume of storage in the HAD reservoir. The lower the annual average storage of the GERD reservoir, the less the evaporation and the seepage losses of the GERD and the less the effect on the downstream Blue Nile flows to Egypt and Sudan. GERD operations 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 (first filling/minimum operating level) of the GERD has the largest impact on the cumulative effect of evaporation losses and seepage during operation; its biggest impact is the reduction of Blue Nile flows to Egypt and Sudan. The agreement among the three countries 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 and not in the filling period, so the real impact of the GERD may occur in the years following the filling and during the operation period. In the long run, all filling scenarios will converge, and the greatest impact of the GERD will be during the drought years of low natural flows of the Blue Nile.

Deficit modeling shows that the current shares of Egypt and Sudan, due to GERD, could be affected and will vary in time according to climate variability impacts on Blue Nile flows within the year, but may also last for periods ranging from 10 to 20 consecutive years during low-flow years due to climate variability from 1 year to another. There is a high level of uncertainty regarding the impacts of climate change when combined with GERD impacts.

## 12 Recommendations

It is critical that the official GERD studies, commissioned by the three countries, be completed promptly so that the parties can agree on the first filling and operating rules to minimize any negative impacts on Egypt and Sudan.

Egypt, Sudan, and Ethiopia must agree on the size of the first filling before consideration of the filling rules. Agreement on the rules of filling must take into account and coordinate the operating rules. The feasibility of reducing the overall size of GERD below the current design size of 74 BCM should be considered to enable operating at low average levels to reduce the negative impacts on Egypt and Sudan downstream, where the maximum storage capacity is only large enough to absorb high flows during the high-flood months.

It is recommended that the volume of the first filling of the GERD should be established at just above the dead storage level, i.e., the lowest storage above which turbines can operate, estimated at less than 15 BCM. It is important to reduce GERD storage to the first filling volume at the end of each hydrological year and to discharge the annual flows 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 impact study on the Blue Nile Basin is needed to reduce the level of uncertainty about the predicted flows, and to assess GERD impacts on downstream countries in light of climate change impacts.

Egypt, Sudan, and Ethiopia must agree on the parameters for the first filling, the operating rules, and the mechanism for coordinating dam management in the three countries. Among the details that are important to include in the agreement is Ethiopia's commitment to limit the use of the GERD reservoir for hydropower generation as per the Declaration of Principles signed by the heads of states to ensure water security for the downstream countries. The three countries must agree to compensation principles that account for the possible negative impacts on Egypt's and Sudan's water shares, rights, existing uses, and hydropower generation from the HAD in Egypt, as well as other dams in Sudan pursuant to the provisions of the Declaration of Principles.

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