Implications of Grand Renaissance Dam on Egypt

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Abstract

Ethiopia has decided to implement the 6,000 MW Grand Ethiopia Renaissance Dam which located on the Blue Nile with storage of 74 BCM. The same site was proposed by the Nile Basin Initiative, to construct "Border dam", with 1,200 MW power plant, and a storage of 14.5 BCM.

The main objective of the paper is to assess the impacts of the different dam alternatives on downstream considering the first impounding and operation cases. It also attempts to identify the optimum dam height that minimizes the anticipated impacts on the downstream.

Nile-DST model will be used to assess the different cases of the dam's alternatives. Different dam's heights and other development projects will be considered to test the whole spectrum of impacts.

The filling of GERD will have significant impacts on HAD if the Ethiopian filling rule is applied. These impacts are exacerbated if filling occurs during drought years. Assessments combining the filling and regulation policy confirm that GERD would cause unacceptably negative impacts on HAD.

HAD level/volume will drastically decrease after the filling period which necessitates long time for the system to be recovered. The alternative GERD sizes demonstrate that smaller GERD heights generally imply less severe impacts on HAD.

Key words: GERD, Border Dam, Blue Nile, discharge, hydropower, Level, Inflow, Energy, scenarios, downstream impacts, HAD .

1. INTRODUCTION

The Nile is a major north-flowing river in north eastern Africa, generally regarded as the longest river in the world. It is 6,853 km long. The Nile is an "international" river as its water resources are shared by eleven countries, namely, Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda. In particular, the Nile is the primary water resource and life artery for Egypt. The Nile River receives its flows from three main distinct watersheds (NBI, 2012); the Equatorial Lake Plateau in the south, the Sudd region in the centre, and the Ethiopian Highlands in the East. From the confluence of Atbara River north of Khartoum to the Mediterranean Sea, the Nile receives no effective inflow.

Egypt is located in an arid zone where rainfall is rare and more than 97% of the water supply of Egypt comes from the Nile River (outside its borders) (FAO, 1997). Blue Nile basin is the major watershed that contributes 58-62 % of the water that arrives at Lake Nasser. Although population growth, agricultural expansion, as well as industrial development and a rise in the standard of living press for additional water resources, the annual quota for withdrawal from the Nile River is fixed at 55.5 BCM since 1959.

The upper Blue Nile basin contains considerable untapped potential for irrigation and hydropower development and expansion. Definitely, the activities on the Blue Nile, such as dams and irrigation, would cause considerable changes in water arrival in terms of quality, quantity, and could have significant impacts on Egypt's economic, social and environmental aspects.

Previous studies by (United States Bureau of Reclamation (USBR), 1964) and recently by the Nile Basin Initiative (NBI) have identified a hydropower dam project on the Blue Nile at the Ethiopian-Sudanese border, with a storage volume of 14.5 BCM and 1,200 MW of hydropower. However, in April 2011 Ethiopia unilaterally announced its plans to build the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile at the very same location of the Border dam about 20 km from the Ethiopian-Sudanese border (Figure 1 shows the locations of the project for GERD), but with an exaggerated storage volume of 74 BCM and 6,000 MW of hydropower. The GERD Project comprises a RCC dam (main dam) with a height of 145 m and Central Core Rock Fill Dam (saddle dam) with a height of 50 m (Table 1: Summary of Main Characteristics of the Project). The main objective of saddle dam is to close the gap between two mountains in order to enlarge the reservoir lake capacity. The GERD Project forms a reservoir with a total storage of some 74 BCM, which represents 1.5 times the entire annual flow of the Blue Nile at the Sudanese border. The dam will definitely have negative impacts on the downstream countries, especially shortage in water demand and hydropower generation during filling and operation.

Figure 1: shows the location of GERD

Table 1: Summary of Main Characteristics of the Project (EEPCO)

Hydrological data	
Mean annual flow	1,547 m3/s
Main Dam Type	RCC dam
Max. Height above foundation	145 m
Crest elevation	645 m asl
Full Supply Level (FSL)	640 m asl
Minimum operating level (MOL)	590 m asl
Total Storage volume	74.01 Bm3
Live storage vol.	59.22 Bm3
Dead storage volume	14.79 Bm3
Saddle Dam Type	Rock Fill Dam
Height	45m
Crest elevation	644 m asl
Unit #/ Installed power	16/375 MW
Max Net Head	133 m
Total Installed Capacity	6000 MW
Average annual energy generation	15,692 GWh/yr
Plant factor	0.31

Study Objective:

The Nile is highly seasonal annual flood, has dominated and shaped the history and economy of Egypt and Sudan from the beginning of time. However, the construction of the GERD can drastically alter this historical Nile flow regime and impact the Eastern Nile region in unprecedented and critical ways. This is because the 59 BCM planned GERD conservation storage, while the mean annual flood volume at the Ethiopian-Sudanese border (Diem) is approximately 49 BCM, most of it occurring during four months of the year. Thus, the GERD will place Ethiopia in a position to exercise a high degree of flow regulation, raising many questions of vital regional interest.

System Description:

To assess the impact of GERD, a model represents the Eastern Nile system was developed. This model encompasses the Eastern Nile system shown in Figure 2 and includes the following reaches (Georgakakos & Yao, GERD-HAD SIM Manual, 2013):

- White Nile inflow contribution at the exit of Gebel el Aulia (Mogren);
- Blue Nile from and including the GERD (near Diem) to Khartoum;
- Atbara River from the Khashm el Girba Dam to the junction with the Main Nile;
- Main Nile from Khartoum to Dongola; and
- High Aswan/Old Aswan Dam complex including the downstream water requirements

This system comprises several components, including hydrologic inflows, reservoirs, river reaches, and water demands, which are modelled as described next.

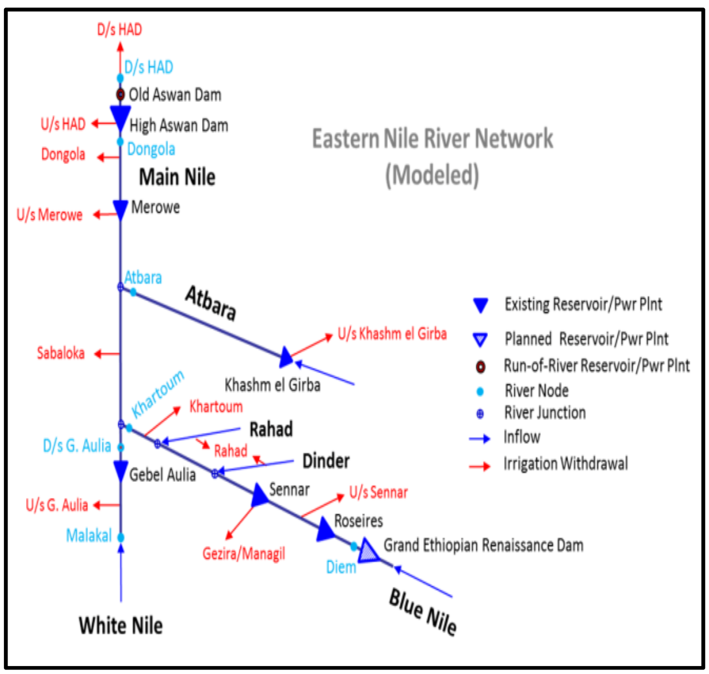


Figure 2: Schematic of System Model (Georgakakos & Yao, GERD-HAD SIM Manual, 2013)

2. METHODOLOGY

GERD, which is being built in Ethiopia, will be imbedded into the system. The dam impacts will be assessed for the filling and operation according to the proposed rules of EEPCO, which proposed to fill the dam on a fixed filling period (six years) and operate to maximize the GERD energy.

The study will also investigate some proposed alternatives aimed at reducing the identified negative impacts, including different dam sizes and different filling periods.

In order to assess the impacts of the GERD, a base case scenario has been considered whereas the existing dams and irrigation schemes were considered. The GERD will be added to the base case scenario, to get its anticipated impact. Results are based on using historical series (1912-2011) include years with dry flows (1980's), as well as years with, average (1912's).

The assessment criteria include:

- GERD energy generation (GWH/yr.) during the filling period;
- HAD elevation (meters);
- HAD water shortage; and
- HAD energy generation (GWH/yr.) during the filling period.

The simulation model simulates the response of the Eastern Nile system including the GERD, five other existing reservoirs (Roseires after heightening, Sennar, Khashm el Girba, Merowe, and High Aswan Dam (HAD)/Old Aswan Dam (OAD complex), and the river reaches connecting the river network.

DATA INPUT

Historical Inflow Sequences:

Impact assessments require system simulations using simultaneous historical naturalized inflow sequences at all input locations (Nile Control Department - MWRI, 1900-2002). The previous system includes five input nodes:

- White Nile inflow at Mogren (at the exit of Gebel el Aulia reservoir);
- Blue Nile inflow at GERD;
- Dinder inflow (Blue Nile);
- Rahad inflow (Blue Nile); and
- Atbara inflow to Khashm el Girba reservoir.
-

Reservoirs and Hydropower Plants:

In addition to the GERD, five existing reservoirs and hydropower facilities were modelled, including Roseires, Sennar, Khashm el Girba, Merowe, HAD/OAD. Some basic features of these facilities are listed in Table 2. The two largest reservoirs are HAD with an active conservation storage of 130.7 BCM and GERD with 59 BCM.

Table 2: Reservoir/Hydropower Parameters

	Max. Operation	Max. Storage	Dead	Dead Storage	Active Storage	Installed
GERD	640	74	590	14.5	59.5	6000
Roseires	490	6	467	0.15	5.85	250
Sennar	421.5	0.9	415	0.18	0.72	15
Khashm	473	0.7	450	0.06	0.64	13
Merowe	300	12.45	285	4.2	8.25	1250
HAD	182	162.3	147	31.6	130.7	2100

Water Demands:

The Sudanese and Egyptian water shares, at Aswan, are 18.5 BCM/yr and 55.5 BCM/yr respectively (PJTC, 1961). The Sudanese water withdrawals take place in various locations (including upstream and from Sennar, the Dinder and Rahad rivers, between Sennar and Khartoum, the Gebel el Aulia reservoir, the Khashm el Girba reservoir, and the Merowe reservoir, among others).

RESERVOIR REGULATION

GERD Filling Rules

Another critical aspect of the GERD construction is the way in which it will be filled. The impacts of the GERD filling period are of significant concern to the downstream countries due to the large reservoir capacity and the high dependence of Egypt and Sudan on the Nile waters. We assessed the EEPCO proposed filling rule (6 years filling) with 640 m filling target in different hydrological cycles (average and drought).

GERD Long Term Regulation Policies

Reservoir regulation policies are important as they can substantially impact the river flow regime, especially when large reservoirs are part of the river network.

The annual Nile flood is a result of the Blue Nile flow seasonality. The mean annual flood volume at Diem station is approximately 49 BCM, with most of it occurring during only four months of the year. With 59 BCM active storage, the GERD regulation potential is of critical regional interest.

Under the current hydrologic conditions without the GERD (baseline scenario), the existing projects follow their standard operating rules developed based on historical, seasonally varying flow patterns. Namely, the regulation of Roseires, Sennar, and Merowe follows seasonal elevation target sequences, repeating year after year. HAD regulation aims to meet the downstream irrigation demand targets with an annual total of 55.5 BCM.

With the GERD in the network, more system wide regulation options are possible. A first such option is to regulate the GERD strictly based on Ethiopian (hydropower) interests without regard for downstream needs.

Regardless of its regulation policy, the GERD is expected to attenuate the historical seasonal flow pattern and make it more uniform. Under such a scenario, the target elevations of the smaller projects (i.e., Roseires, Sennar, and Merowe) do not need to follow the historical fluctuation patters (aiming to flush the sediment and store water for irrigation during flood recession) but can maintain consistent higher water levels. Operating these reservoirs at higher levels will increase energy generation and increase evaporation losses.

ASSESSMENT SCENAIROS AND RESULTS

1) GERD Filling Period Assessments

To determine the sensitivity to different hydrologic conditions, the assessments were carried out for two different river flow sequences. All simulations begin with the HAD initial level at 170 meters, the Sudanese withdrawal target at 18.5 BCM per year, and the Egyptian irrigation target at 55.5 BCM per year. Assessment results summarized in table 3.

Table 3: Filling Period Assessment Statistics; Filling Ending at 640 Meters

Filling Starting Date	Operation Rule	GERD Energy GWH/y	HAD Energy GWH/y	HAD Annual Energy Reduction (GWH)	Energy Reduction %	Av. HAD Level (m)	HAD Elevation Drawdown (m)	HAD Shortage BCM	No. of Years	Max. Shortage / y
1912	EEPCO 6 year	8830	3300	1550	32%	157.2	5.1	35	3	16
	NoGERD	0.00	4850			162.3		-	-	-
1980	EEPCO 6 year	6200	3250	1510	31.7%	156	5.9	68	3	33
	NoGERD	0.00	4800			161.92		10	1	10

Filling GERD up to 640 m Target Level:

In this scenario, the impact of filling the dam with storage capacity 74 BCM by using "EEPCO" rule (6 years filling) with two different river flow sequences was assessed. These sequences include years with very dry flood (1980's), as well as years with, average flood (1912's).

GERD Energy Generation

With the "6 years filling" rule, the GERD power productions are summarized as following:

- With average flood years (1912's), the average GERD energy generation over the filling period is 8830 GWH/yr.
- With dry flood years (1980's), the average GERD energy generation over the filling period is 6200 GWH/yr.

HAD Level Drawdown

The HAD drawdown sequences are illustrated in Figure 3, the drawdown is as follows:

- With average flood years (1912's), the average HAD drawdown over the filling period is 5.1 m. HAD will reach its minimum operating level (147m) for one year.
- With dry flood years (1980's), the average HAD drawdown over the filling period is 5.9 m. HAD will reach its minimum operating level (147m) for approximately two years.

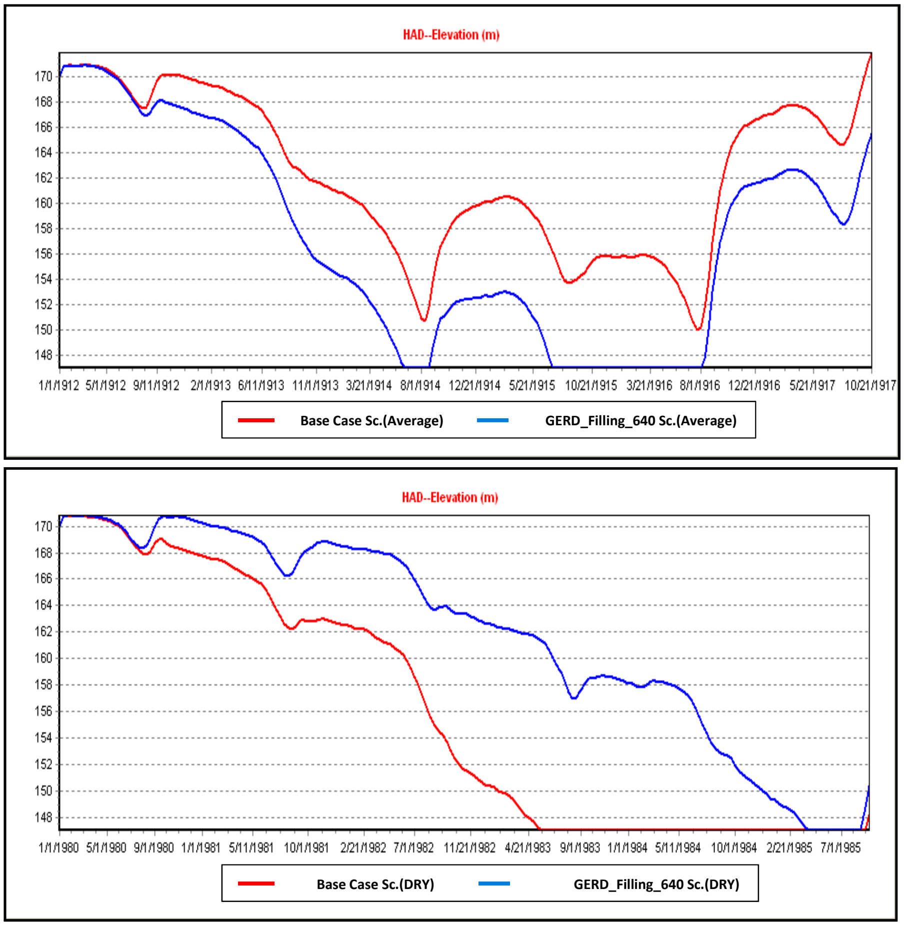


Figure 3: HAD levels during filling and baseline scenarios Starts on 1912 (top)

HAD Water Shortage

With the "6 years filling" rule (EEPCO), figure 4 illustrated the following results:

- With average flood years (1912's), the shortage would reach 34.4 BCM spread over 3 years compared to no shortage for the baseline case.
- With dry flood years (1980's), the shortage would reach 68 BCM spread over 3 years, compared to 9.9 billion cubic meters spread over one year for the baseline case.

HAD Energy Generation

HAD energy generation is bound to experience significant impacts during the filling of GERD, because HAD turbines are shutdown when reservoir elevation falls below 159 meters (Turbines min operational head =50m). Compared to baseline conditions, the average annual HAD energy generation during the GERD filling period would be reduced by 1550 GWH/year under the "6 years filling rule" in average flood condition for the 640 meters filling target. These reductions represent 31.9% of the baseline HAD energy. During droughts the power production would be reduced by 1510 GWH/year of the baseline HAD energy generation.

These impact assessments apply to the filling period only. However, the energy sector impacts will persist beyond filling due to the lower HAD levels. This issue is addressed in the assessment of combined filling regulation scenarios.

GERD Filling Rule Assessment Summary

The results of assessment showed that the EEPCO proposed filling rule (6 years filling) with 640 m filling target have drastic negative impact on Egyptian water resources and the energy of HAD.
Losses due to infiltration to groundwater, during the first impoundment of the GERD were not taken into consideration due to lack of data.
For filling target 640 m and if filling occurs during the average condition (1912's), water shortage could reach up to 35 BCM spread over three years, compared to no shortage for the baseline. And if filling occurs during periods of below average river flows. Water shortage could reach up to 68 BCM spread over three years, compared to about 10 BCM in one year for the baseline.

The impact of GERD filling to the Egyptian energy sector is equally significant, with energy reductions reaching up to 32% of the baseline. Considering a nominal energy replacement cost of 120 million US dollars per 1000 GWH (provided by the Ministry of Electricity), the economic consequences of these reductions are estimated to be in the range 180–200 million U$ per year (over the filling period).

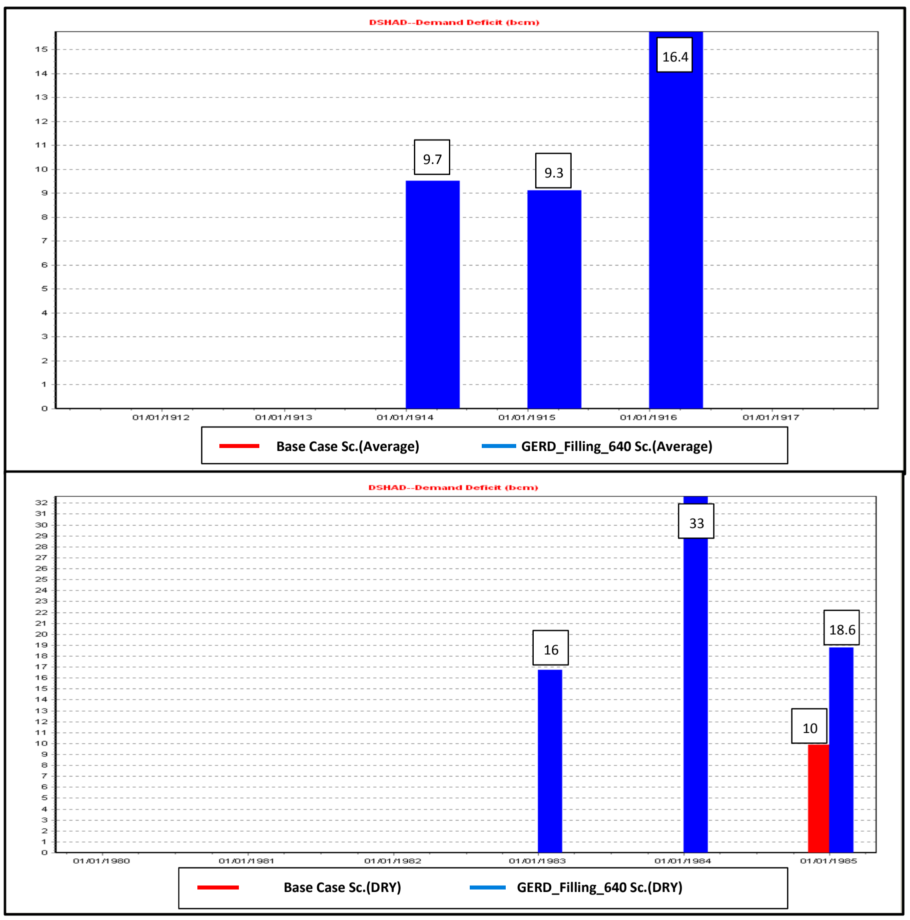


Figure 4: HAD Deficit during filling and baseline scenarios Starts on 1912 (top) and 1980 (bottom)

2) Long Term GERD Impact Assessments

Beyond the filling period, the GERD is expected to influence the Blue and Main Nile flow regimes in an unprecedented ways. As indicated earlier, questions of critical national and regional importance is:

- How will the seasonal Nile flow regime be altered?
- What are the impacts, benefits, and risks of the altered flow regime for Egypt?
- How do these impacts, benefits, and risks depend on the GERD management policy?

The assessments described herein provide quantitative answers to these questions. The scenarios assessed fall in two categories: (1) combined filling and regulation for the entire record period (1912-2011); (2) combined filling and regulation for the critical drought period (1980-2079)

The EEPCO regulation policy is strictly focused on Ethiopian hydropower interests and aims to maximize the GERD energy.

Long Term Regulation Assessment Scenarios

Several scenarios are formulated and assessed in detailed simulation experiments (table 4). The scenarios share the following common elements:

- Simulation horizon: 100 years
- Simulation time step: 10 days
- Reservoirs and initial levels (meters above sea level) is 620 m for GERD, 490 m for Roseires, 420 m for Sennar, 473 m for Khashm el Girba, 300 m for Merowe and 170 m for HAD
- Egyptian Irrigation target: 55.5 BCM/yr.

The scenarios differ in one or more of the following elements:

GERD online status: Baseline scenarios assume that GERD is offline.
GERD Filling policy: The EEPCO proposed rule (6 years filling rule) with filling ending at a level of 640 meters in average flood years (1912's) and drought flood years (1980's).
GERD management policy: Baseline policy is focused on Ethiopian hydropower interests with GERD operating.
Roseires , Sennar, Merowe, and HAD management policies: When GERD is offline, Roseires and Sennar are operated according to their existing operational rules. However, when GERD is online, the seasonal Blue Nile flow regime is altered drastically necessitating that the management of Roseires, Sennar, and Merowe also be altered. In such scenarios, Roseires, Sennar, and Merowe are managed to keep a high storage throughout the year.

Table 4: Scenario Definitions

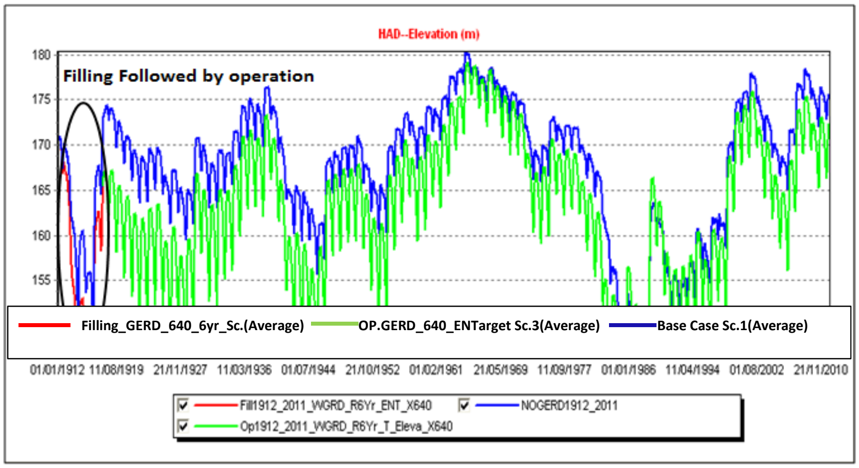
Scenario 1	**Without GERD (1912-2011)**
Scenario 2	**Without GERD (1980-2079)**
Scenario 3	**1912-2011, 6Yr filling, Energy Target, GERD640/590, Filling Ends 640**
Scenario 4	**1980-2079, 6Yr filling, Energy Target, GERD640/590, Filling Ends 640**

Selected simulation sequences for these scenarios over the assessment period (1912 to 2011) are presented in Figure 5 and Table 5. These include GERD energy, and HAD levels, energy, and water shortage sequences. Scenario 1 and 2 represents the baseline conditions with no GERD for the period (1912-2011) and (1980-2079). The results showed that Egypt is already vulnerable to droughts under current conditions and would experience shortage if a drought similar to that of the 1980's re-occurs.

Scenarios 3 and 4 assume a fixed 6-year filling period, maximum GERD energy targets, during average flood years (1912's) and drought years (1980's).

Table 5: Impacts for long term regulation Rules and Sequences; different hydrological conditions

Starting Date	Scenario	GERD Annual Energy (GWH)	HAD Annual Energy (GWH)	Energy Reduction %	Shutdown years of HAD turbines	HAD Shortage (BCM)	No. of Years	Max. Shortage
1912	Scenario 1	-	7121.6	-	13.08	44.6	4	17
	Scenario 3	14641.8	5147.9	27.7	29.92	138.8	14	17
1980	Scenario 2	-	7330.3	-	11.47	39.7	4	25
	Scenario 4	14581.8	5643.9	23	24.58	150.1	11	32.6



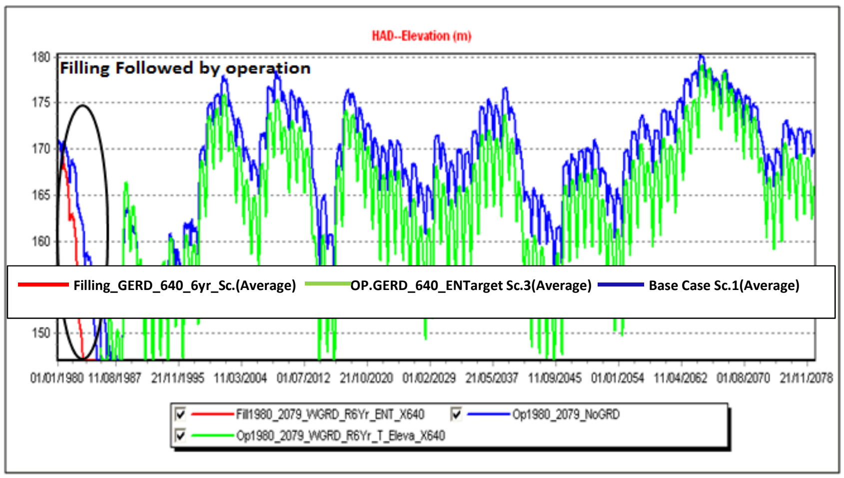


Figure 5: HAD levels for long term regulation and baseline scenarios during average (top) and drought (bottom) flood years

GERD Energy Generation

The GERD power production is summarized as following:

- With average flood years (1912's), the average GERD energy generation over the filling period is 14,642 GWH/yr.
- With dry flood years (1980's), the average GERD energy generation over the filling period is 14,582 GWH/yr.

HAD Energy Generation

The HAD power production are summarized as following:

- With average flood years (1912's), the average HAD energy generation decreases to 5150 GWH/yr compared to 7,122 GWH/yr of the baseline of average flood period
- With drought flood years (1980's) it decreases to 5643 GWH/yr compared to 7,330 GWH/yr of the baseline of drought period.

These reductions corresponding to 27.7% and 23% with average flood years and drought flood years respectively. Due to the increased system losses and lower HAD levels, the total shutdown time of the HAD turbines is estimated at 29.9 and 24.5 years respectively for Scenarios 3 and 4, compared to 13.1 and 11.7 years of the baseline scenarios.

HAD Water Shortage

The assessment results show that Egyptian water shortage is more than three times under Scenarios 3, and 4 versus the baseline of each scenario these can be seen in Figure 6. Total Egyptian shortage amount to 138.9 and 150 BCM under Scenarios 3, and 4 respectively, compared to 44.7 and 39.7 BCM of the baseline scenario in case of average flood and dry flood years. Shortage occurs during the drought of the 1980's, but also during the filling process as described in the previous chapter.

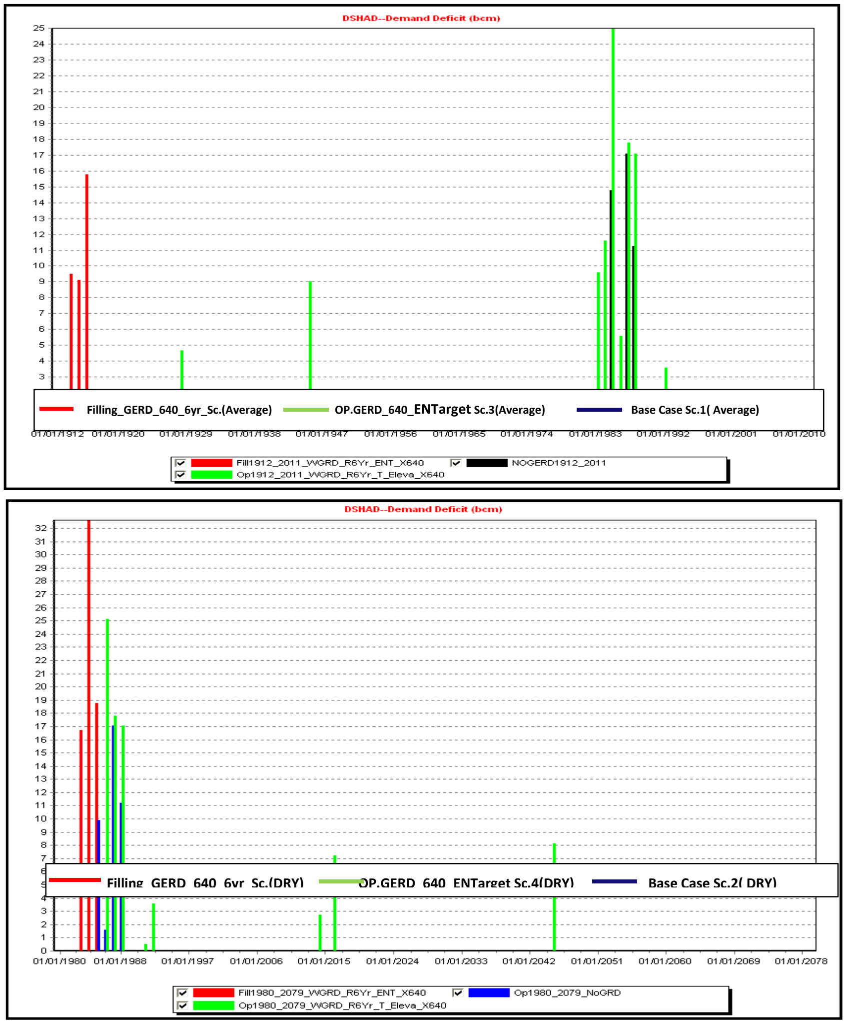


Figure 6: Water shortage of HAD for long term regulation and baseline scenarios during average (top) and drought (bottom) flood years

DIFFERENT ALTERNATIVES OF FILLING PERIODS AND DAM SIZE

In this part, different alternatives for GERD filling periods and dame size were tested, in order to recognize the full range of the negative impacts on HAD.
The impacts of the GERD filling periods are of significant concern to the downstream countries due to the large reservoir capacity, for further investigation to the effect of the filling periods, additional GERD filling periods as well as different dam sizes were tested to assess the impact of GERD on HAD.

This assessment was carried out for a series extends from 1912 to 2011. All simulations begin with the HAD initial level at 170 meters, the Sudanese withdrawal target at 18.5 BCM per year, and the Egyptian irrigation target at 55.5 BCM per year.

1) GERD Filling Periods

Assessment Results

Different filling periods (7– 9 -12) years in addition to 6 years (EEPCO rule) were considered to show the negative impact of GERD, the results with the baseline scenario have been illustrated in Table 6 and Figures 7 to 9.

Table 6: Filling Periods Assessment Statistics; different filling periods

	Rule Option	Filling Years	GERD Energy (GWH)	HAD Energy (GWH)	HAD Annual Energy Reduction (GWH)	Energy Reduction %	HAD Ending level m	HAD Elevation Drawdown (m)	HAD Shortage BCM	No. of Shortage Years	Max. Shortage
1912	6 years	5.8	8830	3300	1550	32%	157.2	5.1	35	3	16
	NoGERD			4850			162.3	-	-	-	-
	7 years	6.7	8905.3	4100	1350	24.8 %	158.8	5	29	3	15
	NoGERD			5450			163.8	-	-	-	-
	9 years	8.7	9384	4650	1526	24.7 %	160.6	5	21	3	13.5
	NoGERD			6176			165.6	-	-	-	-
	12 years	11.7	9356.2	4970	1630.0	24.7 %	162	4.3	13.6	2	11.5
	NoGERD			6600			166.3	-	-	-	-

GERD Energy Generation

Under the "6 years filling" rule, the average GERD energy generation over the filling period is 8830 GWH/yr.
Under the "7 years filling" rule, the average GERD energy generation over the filling period is 8900 GWH/yr.
Under the "9 years filling" rule, the average GERD energy generation over the filling period is 9384 GWH/yr.
Under the "12 years filling" rule, the average GERD energy generation over the filling period is 9356 GWH/yr.

HAD Level Drawdown

HAD level sequences with respect to different filling periods are illustrated in Figure 7. It is noticed that increasing of filling periods would reduce HAD level drawdown. The average HAD drawdown are 5.1, 5, 5, 4.3 m for different filling periods (6, 7, 9, 12 years) respectively.

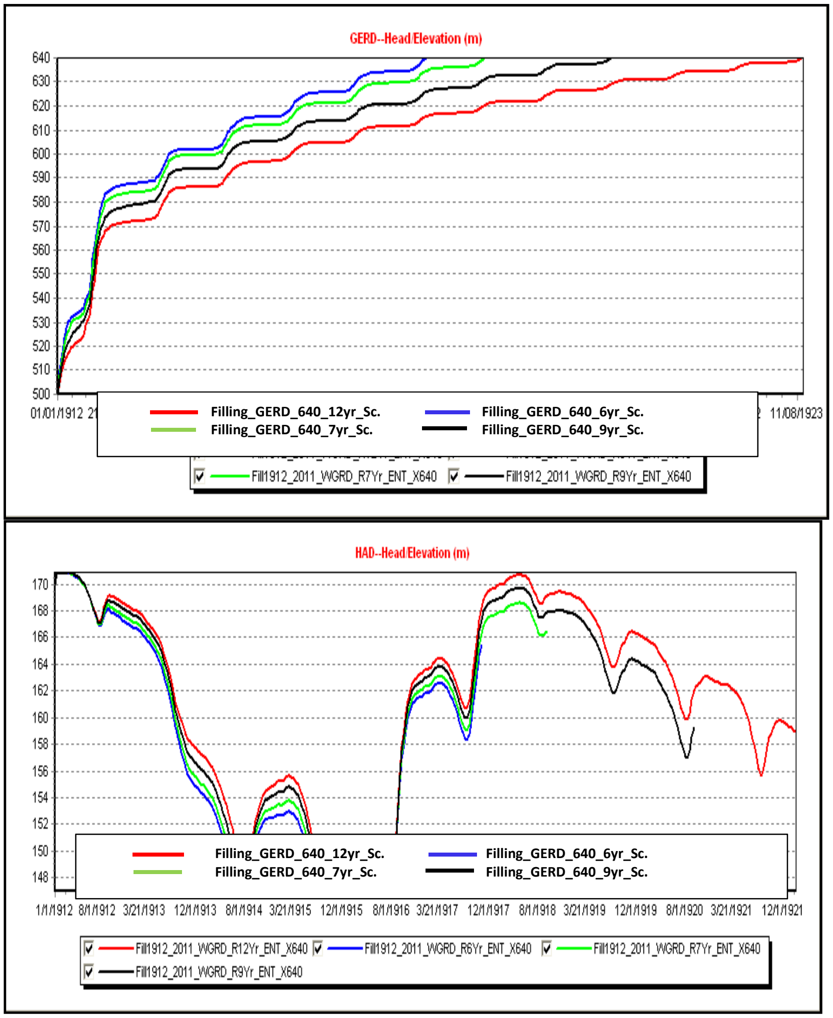


Figure 7: GERD Elevation Sequences (top) and HAD Level Drawdown with different filling periods Starts on 1912

HAD Energy Generation

For the proposed filling periods (6, 7, 9, and 12) years, the HAD energy generation would be 3300, 4100, 4650, and 4970 GWA/Yr for the four filling periods respectively.

HAD Water Shortage

<u>Under the "6 years filling" rule</u>, the shortage would be 34.4 BCM spread over 3 years compared to no shortage for the baseline case.
<u>Under the "7 years filling" rule</u>, the shortage would be 28.8 BCM spread over 3 years compared to no shortage for the baseline case.
<u>Under the "9 years filling" rule</u>, the shortage would be 20.9 BCM spread over 3 years compared to no shortage for the baseline case
<u>Under the "12 years filling" rule</u>, the shortage would be 13.6 BCM spread over two years compared to no shortage for the baseline case. These statistics are summarized in Table 6 and figure 8 and 9.

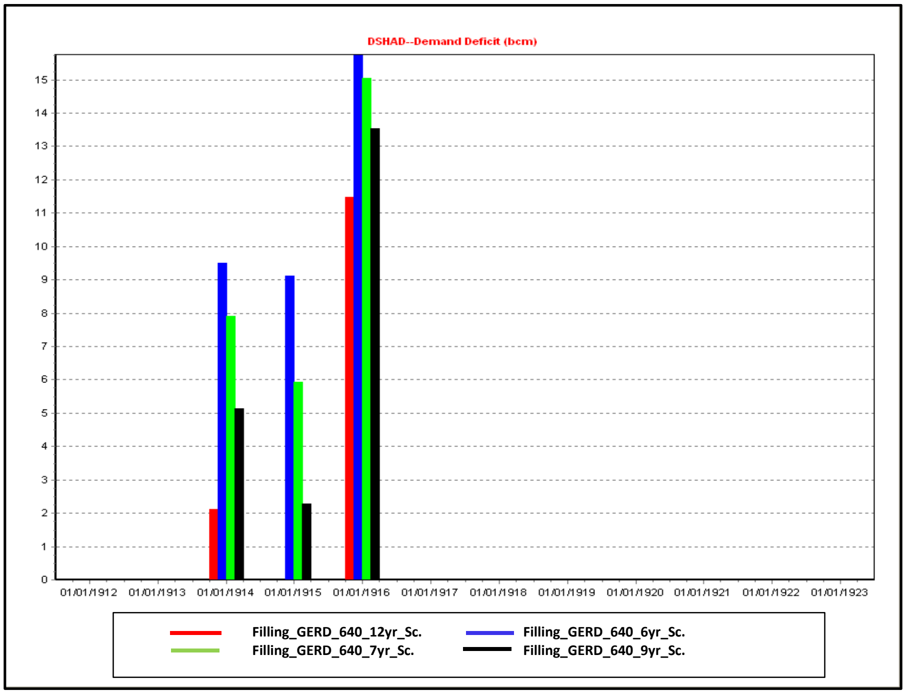


Figure 8: Shortage of HAD (BCM); with different filling periods filling starts on 1912

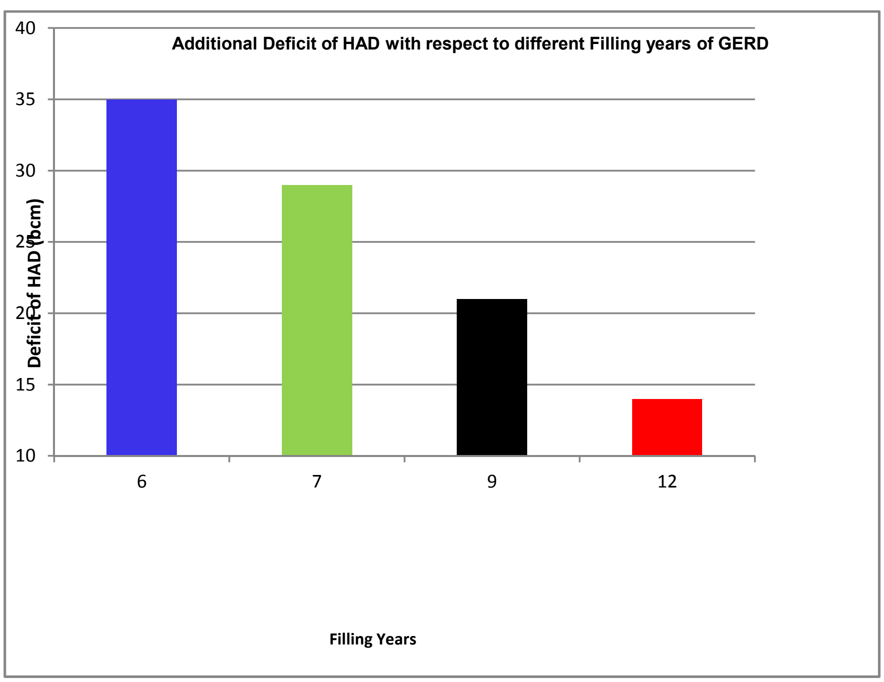


Figure 9 : Shortage of HAD with respect to different filling periods Starts on 1912

Assessment Results

The results showed that the water shortage and power reduction will decreased with increasing filling period but will not be eliminated. If GERD filling happens to coincide with a prolonged drought and the filling target is at 640 meters, the water shortage and power reduction would be increased. These impact assessments apply to the filling period only, however, the energy sector impacts will persist beyond filling due to lowering HAD levels.
Increasing the filling period shows that the water shortage will be proportionally decreased but will not be eliminated, and it depends on the hydrological cycle

2) GERD Different Sizes

Also, to assess the negative impacts of GERD with regards to its capacity, different smaller sizes were tested to assess the impact of GERD. the results with the baseline scenario have been illustrated in Table 7 and Figures 10 to 12.
620 m Filling Target Level: In this scenario, the impact of filling the dam with total storage capacity 43 BCM was assessed.
590 m Filling Target Level: In this scenario, the impact of filling the dam with total storage capacity 14.5 BCM was assessed (Border dam which was studied by the three eastern Nile countries up to the prefeasibility level).

Table 7: HAD Impacts for Filling Rules and Sequences; different dam sizes

<table>
<tr><th>Filling Starting Date</th><th>Filling Level</th><th>Filling Years</th><th>GERD Energy (GWH)</th><th>HAD Energy (GWH)</th><th>HAD Annual Energy Reduction (GWH)</th><th>Energy Reduction %</th><th>HAD Ending level m</th><th>HAD Elevation Drawdown (m)</th><th>HAD Shortage BCM</th><th>No. of Shortage Years</th><th>Max. Shortage</th></tr>
<tr><td rowspan="6">1912</td><td>640</td><td>5.8</td><td>8830</td><td>3300</td><td rowspan="2">1550</td><td rowspan="2">32%</td><td>157.2</td><td>5.1</td><td>35</td><td>3</td><td>16</td></tr>
<tr><td>NoGERD</td><td></td><td></td><td>4850</td><td>162.3</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>620</td><td>5.7</td><td>8330</td><td>3620.0</td><td rowspan="2">1680.0</td><td rowspan="2">31.7%</td><td>158.19</td><td>3.98</td><td>17.63</td><td>2</td><td>9.5</td></tr>
<tr><td>NoGERD</td><td></td><td></td><td>5300.0</td><td>162.17</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>590</td><td>1.5</td><td>2210</td><td>7956.8</td><td rowspan="2">324.8</td><td rowspan="2">3.9%</td><td>167.6</td><td>1.6</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>NoGERD</td><td></td><td></td><td>8281.6</td><td>169.2</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Assessment results

GERD Energy Generation

620 m Filling Target Level: Under the "6 years filling" rule with storage capacity of 43 BCM, the average GERD energy generation over the filling period is 8330 GWH/yr.
590 m Filling Target Level: If we fill the dam with storage capacity 14.5 BCM in one year, the average GERD energy generation over the filling period is 2200 GWH/yr.

GERD Energy Generation:

The GERD power production are 8830, 8330 GWH/yr. for the 640 m GERD filling target and for the 620 m GERD filling target respectively.
The 620 m GERD filling target can generate approximately 94% of energy generated by the 640 m filling target (about 2 times the storage capacity of the 620 m GERD filling target).

HAD Level Drawdown:

The HAD drawdown sequences are illustrated in Figures 11. The figures show that HAD drawdown that become more significant as the GERD filling target level is increased from 590, to 620, and 640 m.

The average drawdowns are 5.1, 3.98 and 1.6 m for different filling Levels (590, 620, and 640 meters) respectively relative to the "NoGERD" baseline. Figure 10 shows HAD levels with respect to different dam sizes.

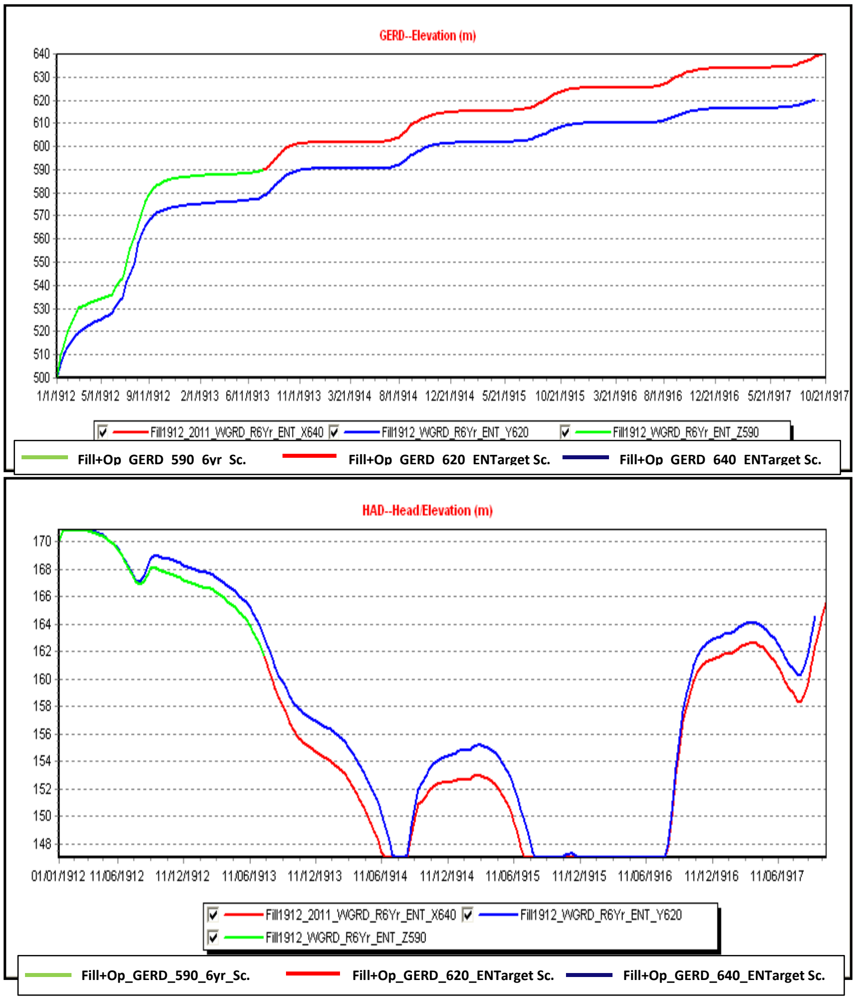


Figure 10: GERD Elevation Sequences (top) and HAD Level Drawdown (bottom); with different dam sizes Starts on 1912

HAD Water Shortage:

<u>620 m Filling Target Level</u>: Under the "6 years filling" rule with storage capacity of 43 BCM, the shortage would be 17.6 BCM compared to no shortage for the baseline case.

The 620 m GERD filling target reduced the water shortage approximately 50% compared to the 640 m GERD filling target, which indicates that the dam size of GERD is not optimized. These statistics are summarized in Table 7 and figure 11 and 12.

<u>590 m Filling Target Level</u>: If we fill the dam with storage capacity 14.5 BCM in one year, there was no shortage in both of filling case and baseline case.

HAD Energy Generation

For the 620 meter GERD filling target, the HAD energy generation reductions would be 32%, and for the 590 GERD filling target the respective reductions would be only 4% .

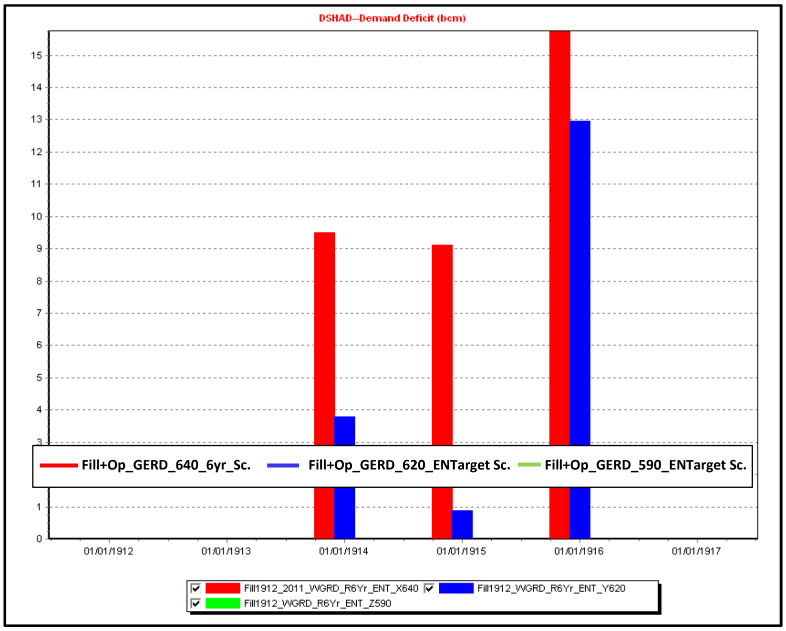


Figure 11: Shortage of HAD (BCM); with different dam sizes; filling starts on 1912

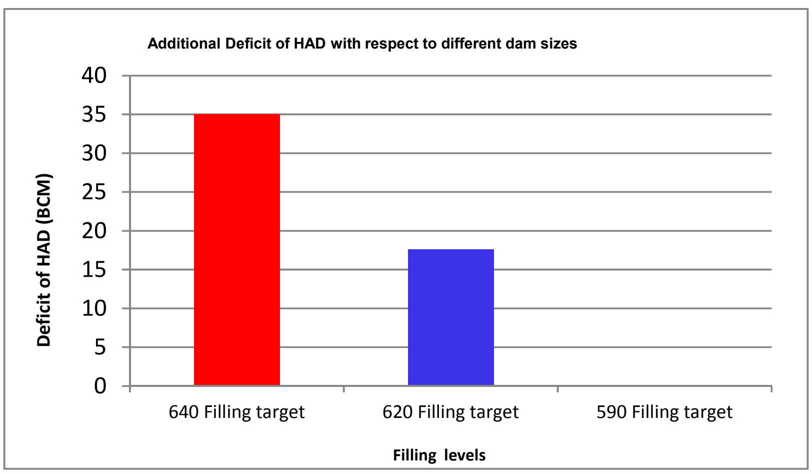


Figure 12: Additional Shortage of HAD with respect to different dam sizes filling

GERD Filling Rule assessment Summary

The assessments showed that the shortage decreased with reduced dam capacity. If GERD filling happens to coincide with a prolonged drought and the water shortage for Egypt would be more severe. The Egyptian water sector adverse impacts are being reduced with smaller dam sizes.

Namely, so it is noted that smaller GERD will accrue smaller impacts.

3. CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

- The Impact of GERD (74 BCM, filling target 640 m) on Egypt was assessed taking into consideration different hydrologic cycles and different operation rules. The filling of GERD will have very significant impacts for the Egyptian water and energy sectors if the Ethiopian six-year filling rule is applied.
- For filling target 640 m and if filling occurs during the Normal condition (1912's), water shortage could reach up to 34.4 BCM spread over three years, compared to no shortage for the baseline. The water sector impacts are most devastating if filling occurs during periods of below average river flows. Specifically, under these conditions and for the1980 hydrologic period, water shortage could reach up to 68 BCM spread over three years. The impact of GERD filling to the Egyptian energy sector is equally significant, with energy reductions reaching up to 32 % of the baseline. Increasing the filling period shows that the water shortage will be proportionally decreased but will not be eliminated, and it depends on the hydrological cycle.
- Assessments combining the Ethiopian filling rule (74 BCM) and regulation policy, for the period (1912-2011), confirm that while the GERD would benefit Ethiopia, it would cause unacceptable negative impacts to the Egyptian water and energy sectors. Water shortage could reach up to 138.8 BCM spread over 14 years (without taking into account infiltration losses to groundwater, during the first impoundment of the GERD), compared to about 44.7 BCM spread over 4 years for the baseline.
- From the standpoint of water shortages, the values of shortage are decreased with increasing the filling period and lowering the dam height
- From the standpoint of HAD energy generation, the values of energy are increased with increasing the filling period and lowering the dam height
- As currently proposed by Ethiopia, the GERD project and associated filling/regulation rules are most likely to harm Egyptian water and power interests and should not be accepted.
- The 620 m GERD filling target can generate approximately 94% of energy generated by the 640 m filling target (about 2 times the storage capacity of the 620 m GERD filling target), which indicates that the dam size of GERD is not optimized, especially that downstream adverse impacts and their associated economic, social, and environmental costs have not been taken into account.
- The storage capacity of the GERD in light of the negative impacts which is not reflected in the same magnitude as in increasing the power generation for Ethiopia, so the dam should be smaller in size for efficiency and cost-effectiveness, also to reduce the negative impact on HAD. This may be win-win situation.

Recommendations:

- Egypt, Ethiopia and Sudan need to negotiate about different dam alternatives for dam size and dam filling in order to mitigate the adverse impact of the project on Egypt.
- Losses due to infiltration to groundwater, during the first impoundment of the GERD is expected to increase the water shortage of HAD and should be considered in further studies
- The potential influence of the proposed cascade development on the flow regime at the GERDP and further downstream needs to be investigated.
- The potential influence of climate changes on the flow regime at the GERDP and further downstream to be investigated.
- The reservoir regulation strategy must be agreed upon with Egypt and Sudan. Such a treaty is absolutely necessary and must be in place before the completion of the GERD project.

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List of Abbreviations

AMSL	above Mean Sea Level
BCM	Billion Cubic Meter
ENTRO	Eastern Nile Technical Regional Office
EEPCO	Ethiopian Electric Power Corporation
FAO	Food and Agriculture Organization of the United Nations
GERD	Grand Ethiopian Renaissance Dam
GWH	Gega Watt hour
HAD	High Aswan Dam
MOL	Minimum Operation Level
MW	Mega Watt
NBI	Nile Basin Initiative
NB DSS	Nile Basin Decision Support System
Nile-DST	Nile Decision Support Tool
OAD	Old Aswan Dam
USBR	United States Bureau of Reclamation